INTELLECTUAL PROPERTY ISSUE

Technology Review
MIT's Magazine of Innovation

Who Will Own Ideas?

The People Who Use Them.
Lawrence Lessig p46

The People Who Create Them.
Richard Epstein p56

Not Microsoft!
Charles Ferguson p64

It's Complicated...
The editors p18



Plus

Can Tech Make Crowds Smart?
By Michael Fitzgerald p80

What Digital Maps Know about *You*
By Daniel Charles p77

How Bluetooth Is Saving UPS Millions a Year
By Tom Mashberg p42

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Contents

Volume 108, Number 6

7 **People and Organizations Index**
A guide to what's in this issue

12 **From the Editor**
Star Wars: Revelations and copyright

14 **Letters**
Your thoughts on race and medicine, Arctic drilling, and more

README
Read before operating this magazine

18 **Who Should Own Ideas?**
The courts and legislatures should preserve copyright—but carefully.

19 **Big Steps for Small Things**
It's time to pick nanotech winners.

19 **Market Injection**
Nongovernmental organizations can meet a need in the vaccines market.

FORWARD
Emerging technologies in brief

21 **Tagging Is It**
A wiser way to navigate the Web

22 ***In Silico* Immunology**
Melvin Cohn uses computers to clarify one of biology's most confusing fields.

24 **Design by DNA**
Ned Seeman's twist on manufacturing

25 **The Customer Is Always Right There**
Reactrix Systems changes advertising.

28 **Instant Networks**
PacketHop's technology on the go
And more...

DATA MINE
A story best told with numbers

31 **Nanotech Grows Up**
Funding for R&D doubled in 2004.
By Stacy Lawrence

Who Will Own Ideas?

This month, we host a debate between two leading intellectual-property lawyers whose opposing views on copyright give shape to one of technology's most pressing issues. We also feature a piece by entrepreneur Charles Ferguson on the greatest current threat to proprietary software: Linux.



46

DEALFLOW
Who is investing where

33 **Funding of Innovative Startups**
Clearwire, Nanomix, and more
By Andrew Madden

FINANCIAL INDICES
The *TR* Large-Cap 100 and Small-Cap 50

35 **Pain Relief (for Some)**
Pharma feels great—for now, anyway.
By Duff McDonald

BRIEFCASE
Business case studies

36 **The Vaccine That Almost Wasn't**
GlaxoSmithKline's Rotarix
By Jim Kling

39 **Preventing "Fratricide"**
Raytheon's troubled Patriot missile
By David Talbot

42 **One Decision: UPS Goes Bluetooth**
By Tom Mashberg

BY INVITATION

43 **Good-Bye to Venture Capital**
Technology finance has turned rational—so I'm outta here.
By Howard Anderson

FEATURES

46 **The People Own Ideas!**
Do we want music, software, and books to be free—or not?
By Lawrence Lessig

56 **The Creators Own Ideas**
A truly free society allows for proprietary systems.
By Richard A. Epstein

63 **Lessig's Rebuttal to Epstein**

64 **How Linux Could Overthrow Microsoft**
The open-source movement is the largest threat the software giant has ever faced. Does Bill Gates have a plan?
By Charles Ferguson

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Contents



70

DEMO
Breathtaking medical imaging
The latest advances give very clear pictures.



80

REVIEWS
Mass communication
Technology is changing the whole crowd.



42

BRIEFCASE
UPS's newest gadget
It combines Bluetooth and Wi-Fi to allow workers to scan packages wirelessly.

DEMO
Technology revealed

70 **Body Image**
The latest medical-imaging advances provide unprecedented diagnostic power—and they're visually stunning.
By David Talbot

MEGASCOPE
A look at the big picture

76 **Rise of the Plagiosphere**
How new tools to detect plagiarism could induce mass writer's block
By Ed Tenner

REVIEWS
Three ideas explored

77 **Do Maps Have Morals?**
Digital mapping is an invaluable tool—but it's partly rooted in Cold War schemes for mutual annihilation.
By Daniel Charles

80 **Group Rethink**
Can technology raise society's IQ?
By Michael Fitzgerald

82 **Cybernought**
The founder of cybernetics is largely forgotten. That's a pity.
By Mark Williams

FROM THE LAB
New publications, experiments, and breakthroughs—and what they mean

83 **Information Technology**

84 **Biotechnology**

87 **Nanotechnology**

TRAILING EDGE

88 **The Start of Computer Games**
Created at MIT, Spacewar inspired future game pioneers.
By Corie Lok

What's new at technologyreview.com

In the May issue of the magazine, Stewart Brand's piece "Environmental Heresies" argued that environmentalists needed to change their stance on four controversial issues: population growth, urbanization, genetic engineering, and nuclear power. Brand's essay caught the attention of former U.S. Department of Energy official and MIT-trained physicist Joseph Romm, who started a dialogue with Brand. We found it fascinating, and thought you might as well, so we launched a blog (brand.trblogs.com) where the two could hash out their differences in public.

We also updated our own blog (www.trblogs.com) using MovableType, which will allow readers to better browse through commentary from reporters, editors, and friends of *Technology Review*.

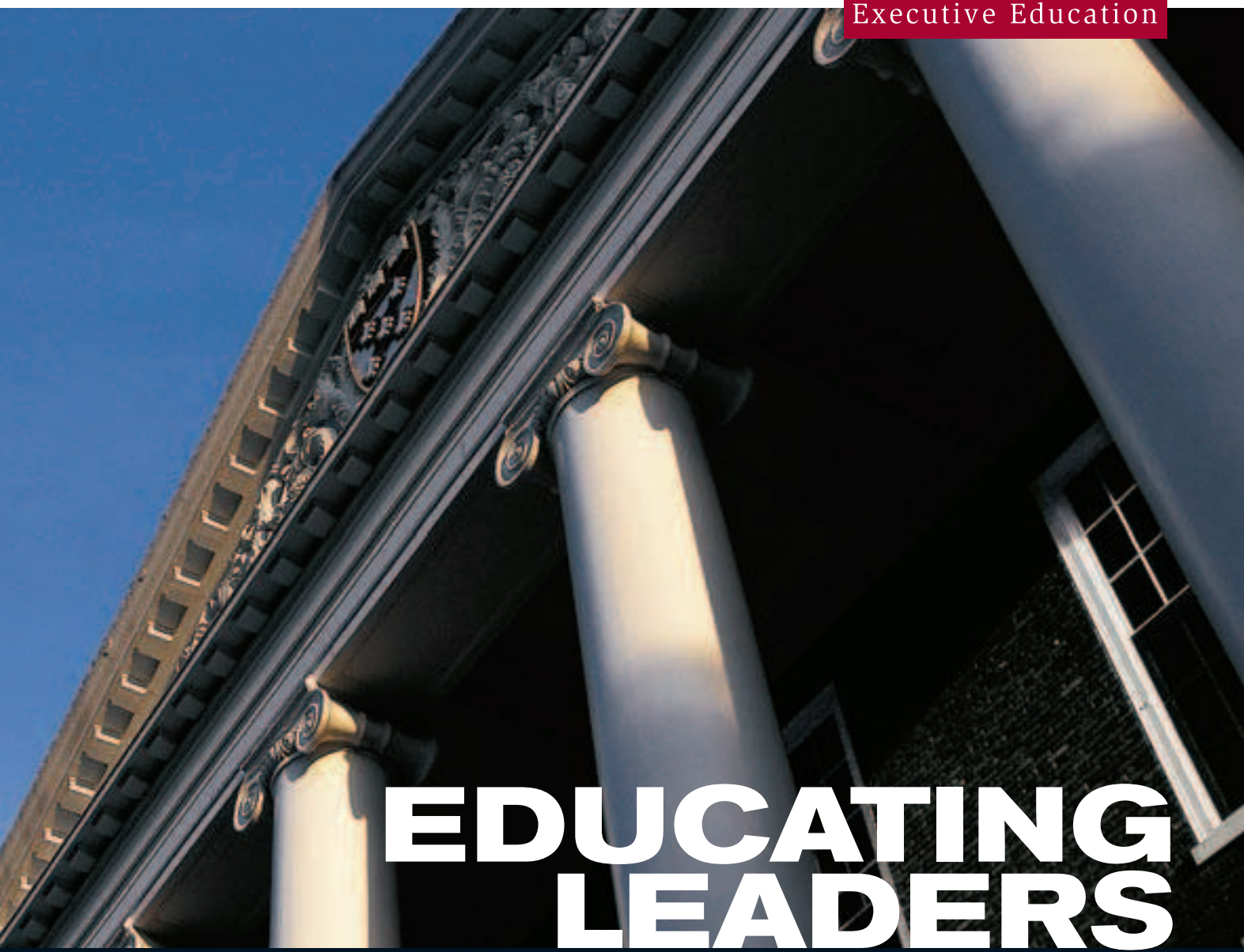
We're even opening up our editorial doors. Starting this month, editor in chief Jason Pontin (pontin.trblogs.com) and Web editor Brad King (king.trblogs.com) will enter the blogosphere.

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People and Organizations

PEOPLE

Aebischer, Patrick, tag-teaming gene therapies and 85
Albrecht, Manfred, future hard drives and 87
Amen, Daniel, on photographing inner demons 27
Anderson, Colin, immunologist 23
Ayers, Lawrence, head of U.S. Defense Mapping Agency 78
Bach, Francis, isolating speech signals and 83
Barlow, John Perry, Electronic Frontier Foundation cofounder 48
Bell, Matt, as father of Reactrix 25
Bellow, Saul, as inspiration 60
Blair, Jayson, as software inspiration 76
Bush, George H. W., as missile-defense booster 39
Bush, George W., fund-raising and 81
Bushnell, Nolan, as King Pong 88
Caouette, Jonathan, as iMovie maker 52
Chait, Norm, on ads as sundae topping 26
Chrisman, Nicholas, digital-mapping historian 79
Cloud, John, on Cold War mapping 78
Cohn, Melvin, immunology conceptualist 22
Conway, Flo, *Dark Hero* author 82
Cornett, Dion, on OS development costs 68
Cox, David, genome mapping and 84
Coyle, Philip, on warware glitches 40
Dangermond, Jack, as digital environmentalist 78
De Vos, Beatrice, on manufacturing a vaccine 37
Dean, Howard, as political blog roller 81
Edwards, Dan, as gravity gamer 88
Einstein, Albert, Brownian motion and 82
Emborg, Urban, as glassic rocker 25
Epstein, Richard, as DRM capitalist 50
Fonda, Jane, as Hanoi Jane 81
Friedberg, John, Reactrix cofounder 25
Gates, Bill, benevolent gaze of 58
Gershwin, George, copyright extensions of 60
Gil, Gilberto, Brazil's minister of culture, rocker 52
Gillmor, Dan, *We the Media* author 81
Graetz, J. M., as hyperspace jumper 88
Hardy, G. H., mathematician 82
Hegi, Monika, more-effective chemo and 85
Hemingway, Ernest, as novel inspiration 60
Hilbert, David, mathematician 80, 82
Howse, Michael, on networking in a disaster 28
Hussein, Saddam, arsenal of 39
Hutchinson, G. Evelyn, Earth's equilibrium and 76
Jakobi, Nick, speed-reading software and 27
Jordan, Michael, isolating speech signals and 83
Kennedy, Robert F., as teen idol 53
Kerry, John, as superimposed protester 81
Killeen, John P., UPS director of global network services 42
Koogle, Tim, Reactrix investor 26
Langman, Rodney, protectons and 23
Lebesgue, Henri, influential mathematician 82
Lennon, John, as proto Bono 53
Lessig, Lawrence, as copyleftist 58
Lippman, Walter, newsman 81
Locke, John, on natural rights 59
Mackay, Charles, *Madness of Crowds* author 80
Main, Kevin, friendly-fire casualty 39
Malone, Thomas, *The Future of Work* author 80
Mata, James, sim-antibodies and 23
Matzinger, Polly, immunologist 22
McCaw, Craig, Clearwire CEO 33
McDonald, John, Nanomix CEO 33
McHarg, Ian, landscape architect, essayist 78
McVoy, Larry, BitMover founder 68
Myers, Deborah, on manufacturing a vaccine 37
Nash, Glen, public-safety tech specialist 28
Nonneman, Robert, RFID critic 42
Palmisano, Sam, IBM CEO 35
Pike, John, on unprepared Patriots 40
Postol, Theodore, on unprepared Patriots 40
Rheingold, Howard, on smart mobs 81
Richman, Debby, tag buyer 22
Rogers, Fred, Mr. Rogers' testimony 60
Rollet, Pierrick, on distributing a vaccine 38
Rosenfield, Donald B., RFID proponent 42
Rumsfeld, Donald, as hypothetical sore thumb 52
Russell, Bertrand, logician 82
Russell, Steven, as space warrior 88
Sachs, Wolfgang, on NASA's snapshots 76
Salzman, David, UPS wireless manager 42
Samson, Peter, as star programmer 88
Sastry, Ambatipudi, PacketHop founder 28
Satlof, Phil, digital mapmaker 77
Schachter, Joshua, Delicious maker 21
Seeman, Ned, on PC DNA 24
Shields, Guy, on missile problems 40
Siegelman, Jim, *Dark Hero* author 82
Simpson, Christopher, on remote sensing 77
Song, Kwang Yong, slowing light in optical fiber and 83
Stallman, Richard, open-source crusader 14, 48, 59, 66
Stanforth, Peter, as Motorola mesh networker 28
Stockbauer, Hannah, as MRI scan model 71
Stupp, Roger, more-effective chemo and 85
Surowiecki, James, *Wisdom of Crowds* author 80
Teng, Apollo, digital mapmaker 77
Tiemann, Michael, Red Hat VP of open-source affairs 67
Torvalds, Linus, as kernel sprouter 49
as antivisionary 64
Trippi, Joe, as iUtopian 81
Vernadsky, Vladimir, "biosphere" origin and 76
Ward, Richard, rotavirus vaccine developer 36
Weber, Steve, open-source consultant 69
Weinberger, David, Web pundit on tagging 22
White, Nathan, friendly-fire casualty 39
Whitman, Meg, eBay CEO 35
Wiener, Norbert, as "Dark Hero" 82
Williams, David, friendly-fire casualty 39
Zhang, Junliang, efficient fuel cells and 87

ORGANIZATIONS

AES 81
American Society of Composers, Authors, and Publishers 69
Atari 88
Avant Immunotherapeutics 36
Bill and Melinda Gates Foundation 37, 58
BitMover 68
Boeing 23
BP 81
Brookhaven National Laboratory 87
Caran 25
Centre Hospitalier Universitaire Vaudois 85
ClairVoyante 23
Clearwire 33
Computer History Museum 88
Corpora Software 27
Delicous 21
Dell 66
DHL 42
Digital Equipment Corp. 88
Dilithium Networks 33
Disney 51, 60
eBay 35, 80
École Polytechnique Fédérale de Lausanne 83, 85
Electronic Arts 35
Electronic Frontier Foundation 48
ESRI 77
European Organisation for Research and Treatment of Cancer 85
Evolva Biotech 33
First Calgary Petroleums 35
Flickr 21
Free Software Foundation 48, 66
Furl 21
General Electric 70
Gesturetek 26
GlaxoSmithKline 37
Global Alliance for Vaccines and Immunizations 36
Google 80
Grateful Dead 48
Grokster 18, 60
Hewlett-Packard 48, 66
Hitachi 87
IBM 26, 35, 48, 59, 66
Intel 66
JBoss 67
Kraft Foods 42
Linspire 67
Lockheed Martin 39
Looksmart 21
Mandriva 67
Merck 35, 36
MeshNetworks 28
MGM 18, 60
Microcell Telecommunications 33
Microsoft 46, 58, 64
MIT 48, 59, 66, 82, 88
Morton Thiokol 80
Motorola 28
Mozilla Foundation 67
MySQL 67
Nanomix 33
NanoOpto 33
Nantero 33
NASA 76
National Venture Capital Association 43
Navteq 77
Nestlé 42
New York University 24
Nextnet Wireless 33
Novell 67
Open Source Development Labs 67
Oracle 66
PacketHop 28
Perlegen Sciences 84
Pfizer 35
Public Library of Science 69
Raytheon 39
Reactrix 25
Red Hat 67
Rojo 21
Salk Institute for Biological Studies 22
Siemens 70
Slashdot 81
Sony 60
SRI International 28
Stanford University 25, 88
Sun Microsystems 64
Symbol Technologies 42
TelAsic 33
TolerRx 33
TopoTarget 33
Toys R Us 25
Tufts University 82
United Parcel Service 42
Universal Studios 60
University of California, Berkeley 83
University of Konstanz 87
University of Utah 88
University of Wisconsin-Madison 87
U.S. Army 39
U.S. Centers for Disease Control and Prevention 36
U.S. Department of Defense 39, 77
U.S. Food and Drug Administration 36
U.S. Navy 23, 80
U.S. Supreme Court 60
World Economic Forum 26, 48
World Health Organization 36
World Social Forum 48
Wyeth 36
Yahoo 21



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Digital Properties

THIS APRIL, I saw a wonderful new Star Wars film. It wasn't made by George Lucas. I watched it for free, having downloaded a digital file, and I broke no copyright laws.

Star Wars: Revelations is a work of delirious fandom: a 40-minute homage by amateur filmmakers that imagines the interval between *Star Wars Episode III: Revenge of the Sith* and the original *Star Wars* (now *Episode IV: A New Hope*).

Revelations is a "remix." It has all a Star Wars movie should: packs of Imperial fighters, light-saber duels, a sobbing orchestral score. It exists only because George Lucas waived many of the traditional privileges of the copyright owner. So long as the filmmakers did not sell the movie, they were allowed to freely reuse most of the elements of the Star Wars universe.

Lawrence Lessig, a professor of law at Stanford University and a famous proponent of more-relaxed copyright regulations, praises this kind of free cultural reuse in an essay in this month's package on intellectual property *(see "The People Own Ideas!" p 46)*: "Many more people (indeed, millions more) could make good films. New digital technologies could enable an explosion of creative work."

Lessig goes further: he argues that remixing is "how culture gets made." He writes, "It is almost impossible to imagine a culture thriving if its people are not free to engage in this kind of practice." But he also worries that new digital rights management (DRM) technologies will make remixes like *Revelations* dependent on the permission of enlightened copyright owners like Lucas—and, therefore, vanishingly rare.

Lessig's point is subtle. To see its force, one must understand how far copyright regulation has expanded its scope. Additionally, one must grasp a peculiar property of digital technologies.

U.S. copyright law has its origins in the technology of the industrial era: it was originally designed to govern the operations of printing presses. At first, few cultural artifacts were regulated: only books, maps, and charts. But copyright has grown to regulate more media, and after the Copyright Act of 1976, *all* tangible creative work was automatically protected by copyright.

Still, before the digital era, copyright law did not affect the ordinary uses of cultural artifacts. Reading or sharing a book was not regulated, because no copy was made. But it is a property of digital technologies that *every* use of a creative work produces a copy—one that can be shared with millions of other people.

DRM technologies would, of course, ensure that copyright owners are paid after years of near universal piracy. But they would do more: allow the enforcement of the hitherto notional 1976 Copyright Act. In Lessig's elegant formulation, "When the Internet gives copyright owners perfect control of their content, then, since it's all automatically copyrighted, every use of it will presumptively require permission."

Lessig is so appalled by this prospect that he advocates a "free-culture movement" based on the free-software movement that spawned Linux *(see "How Linux Could Overthrow Microsoft," p. 64)*. Lessig salutes the Brazilian government's recent support of free culture in its policies and procurements.

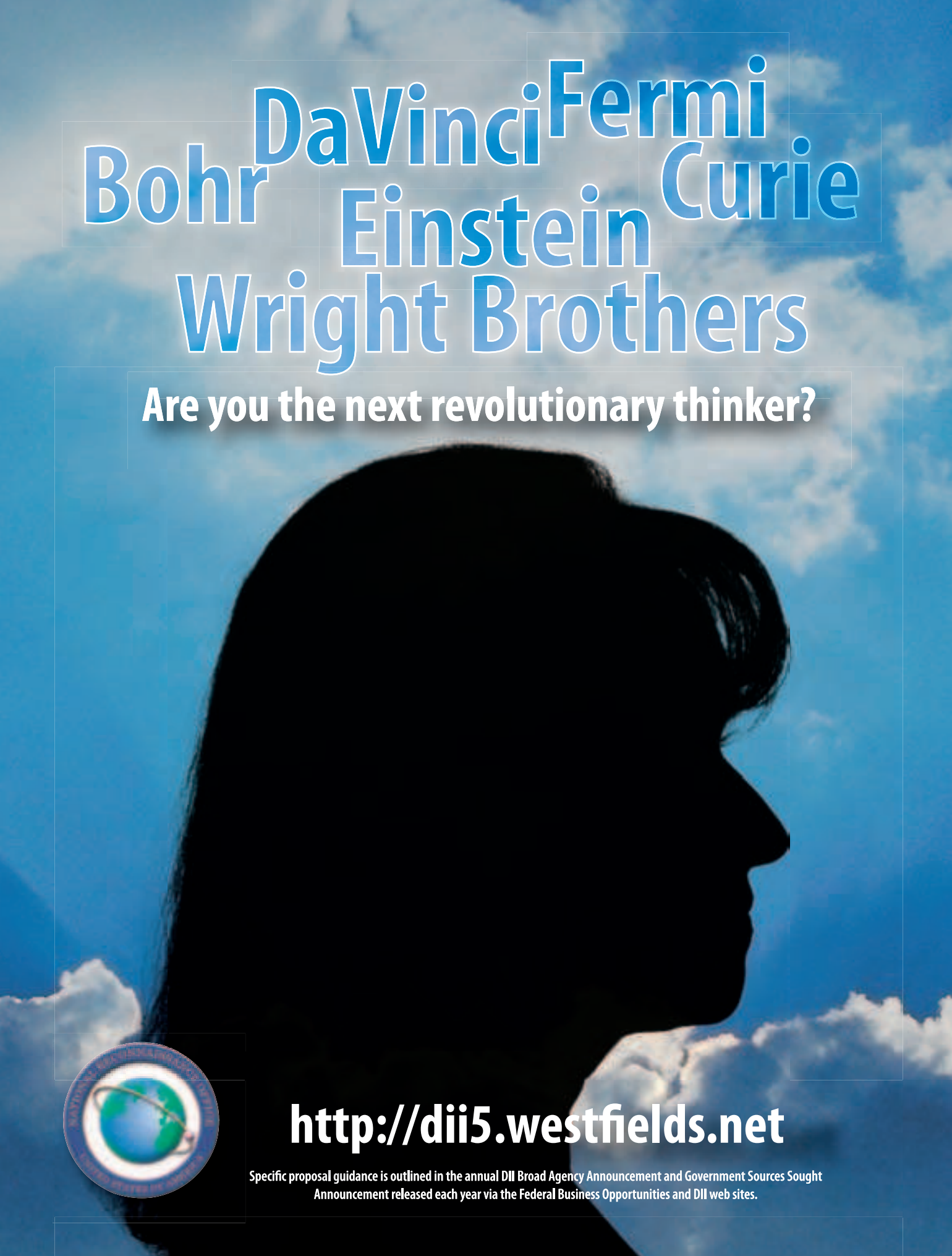
Richard Epstein, professor of law at the University of Chicago and a noted champion of the power of markets, has serious objections to this line of reasoning. In a rejoinder to Lessig, "The Creators Own Ideas" *(see p. 56)*, he rejects the "wholly illiberal" idea that the government, whose proper role is to be a neutral arbiter, should favor one mode of business over another. He also contends that rather than thwarting creativity, proprietary systems encourage it by providing financial incentives.

Digital rights management technologies would guarantee that creators are rewarded for their labors. They would allow sellers to price their products according to their use.

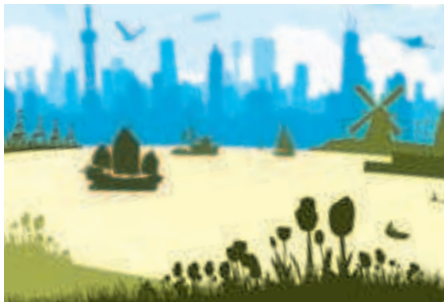
Who is right? Surely, there is truth on both sides. Indeed, both Lessig and Epstein acknowledge that there have always been private and commonly owned ideas; both tacitly accept that this is unlikely to change in the digital era. Both wish to see a society that preserves reasonable and limited copyrights, while simultaneously abjuring extreme limits on individuals' ability to "remix" culture. They want a copyright system appropriate for the digital era.

But Lessig is too alarmist about DRM technologies: they will not make remixing "impossible." More importantly, they would allow what economists call "price discrimination," the ability of sellers to price their products according to their use. This is a useful innovation for digital economies: someone who wanted to keep an e-book, for example, could be charged more than someone who only wanted to read it once.

A strong argument against Lessig is that *Revelations* was remixed from cultural material held under one of the most profitable traditional copyrights of all time. Proprietary systems don't necessarily discourage innovation. Perhaps, rather, the reverse. Am I wrong? Write to jason.pontin@technologyreview.com. ■


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Letters



WORLDWIDE TECHNOLOGY

Ken Morse is correct: spending enough money on security technology is bound to spawn many useful innovations ("World-Changing Ideas: United States," April 2005). But why not put that money directly into R&D on health care or the environment, and see what technologies emerge for security applications?

Val Livada
Winchester, MA

What's up with the picture of the elephant and giraffe in your article about South African technology? South Africa isn't a wildlife park; we don't step out of our back doors and see lions and eagles. This illustration is like using a picture of a Native American to sum up the United States.

Gregg Stirton
Cape Town, South Africa

RACIAL MEDICINE

The debate about race and medicine is more about political correctness than good medical practice ("Race and Medicine," April 2005). No competent doctor would rely on race alone in prescribing drugs; race would just be an indicator as to which drug to try first. Until more progress is made in testing for individual susceptibilities, why shouldn't the doctor use all the information available in determining a course of treatment?

Clay W. Crites
West Chester, PA

SHORT-SIGHTED DRILLING

In assessing the ecological impact of drilling in the Arctic National Wildlife Refuge, Bryant Urstadt does not weigh the expected benefits, which are temporary, against the potential losses, which would be permanent ("Wild Profits," April 2005). Factoring this into the equation clearly argues against drilling. Imagine if our predecessors had gambled Yellowstone or the Grand Canyon in this way. The brief bonanza of minerals or lumber long forgotten, how much poorer as a people would we be today?

Josh Adelson
Sharon, MA

UNDERWATER AC/DC

The story about laying an electric-power transmission line across Long Island Sound ("TransÉnergie: Playing Two Power Games," April 2005) reminds me of a conversation I had in 1969 with the head of Finland's power company. For a number of reasons, the Finns were buying electric power from the Russians, whose grid had major fluctuations in voltage and frequency. This was causing serious problems with matching the AC power lines. The Finns had therefore installed DC transmission lines as buffers between the two grids. This allowed conversion between AC and DC, eliminating the problems caused by variations in the Russian system. It was a neat solution to a serious engineering problem—a benefit that will also accrue from systems such as the Cross Sound Cable.

William L. R. Rice
Fredericksburg, VA

ALMOST HUMAN

There is really no puzzle as to why *The Polar Express* didn't work ("Freeze Frame," April 2005). First, expanding the charming short story into a feature-length film required an amazing amount of padding, and the result was that the plot felt—well, padded. Second, while obvious caricatures in an animated film can be charming (think *Shrek*), characters that look almost, but not quite, human are simply creepy. A padded holiday movie full of creepy characters is not very likely to be a box office hit.

John Prusinski
Warwick, NY

CHEERLEADING FOR THE MILITARY?

The photo essay "Online at Centcom" (April 2005) continues *Technology Review*'s pattern of cheerleading for military technology by showcasing glowing visions and remarkable achievements but omitting the thoughtful analysis that the magazine gives to other technologies. Has *Technology Review* downsized to summarizing military technologies rather than "analyz[ing] their commercial, economic, social, and political impact," as it purports to do on the table-of-contents page?

Dave Rhoads
Needham, MA

IP OR NOT IP

Simson Garfinkel's review of books about hacking mispresents my views ("Hack License," March 2005). For example, Garfinkel's description of the Free Software Foundation's list of frequently misused terms (a set of suggestions that he wrongly equates to forcibly imposed censorship) implies that we entirely reject words such as "consumer" and "commercial." In fact, we don't object to the word "consumer," but we urge people not to assume that software users are just consumers. Neither do we object to "commercial," but rather correct the misconception that free-software advocates oppose "commercial software" (see www.gnu.org/philosophy/words-to-avoid.html). Garfinkel also errs in referring to a "Wark-Stallman view" of "intellectual property." I don't know where author McKenzie Wark stands, but I have no view about "intellectual property," because the term lumps together laws covering copyright, patents, and trademarks, which have little in common.

Richard Stallman
President, Free Software Foundation
Cambridge, MA

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SOFTWARE

Who Should Own Ideas?



This spring, lawyers for MGM Studios argued before the U.S. Supreme Court that Grokster, the maker of a peer-to-peer Internet file-sharing system, should pay damages to copyright holders for facilitating mass piracy of their digital content.

One simple fact underlies the current debate over intellectual-property rights, the theme of this special issue of *Technology Review*: every time you download a music file or use some other artifact of digital culture, you are making a copy. If you don't have permission, or the use is not "fair" (that is, very limited), you may be breaking the law and infringing the rights of copyright owners. Until recently, there was little that copyright owners could do about it; but there are now effective digital rights management (DRM) technologies designed to limit copying, remixing, and redistribution. Is this increase in the potential power of copyright owners a good thing?

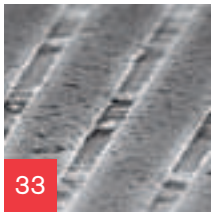
Stanford University law professor Lawrence Lessig, who submitted a friend-of-the-court brief in the Grokster case, leads off with an essay on copyright and free expression. Healthy societies, Lessig argues, give citizens the freedom to "remix" bits and pieces of copyrighted works such as songs, writings, images, and software *(see "The People Own Ideas!" p 46)*. But today, he warns, those very bits and pieces are disappearing behind DRM technologies. If communities want to hold onto their ideals of open communication, Lessig says, they should look to the free-software movement, which encourages software developers to let anyone run, analyze, adapt, improve, and redistribute their code.

It's an attractive vision—but an idealistic one, according to Richard Epstein, a professor at the University of Chicago Law School, where he and Lessig were once colleagues *(see "The Creators Own Ideas," p. 56)*. Epstein asks where Lessig expects to find his free-culture volunteers if they must give up their livelihoods—that is, their exclusive right to profit from their own intellectual labor—in the process. Without state-enforced copyrights, there's little incentive to create, argues Epstein.

Finally, we turn to a more pragmatic argument for free culture. Charles Ferguson, who wrote about the threat to Google from Microsoft in our January issue, now writes about the threat to Microsoft from Linux and other products of the open-source movement, a direct descendant of the free-software movement *(see "How Linux Could Overthrow Microsoft," p. 64)*. Releasing its products under open-source licenses isn't just good karma for a software company, Ferguson concludes: it's good business.

U.S. society seems destined to divide into two camps: communities that thrive on free copying and others that profit from copyrights. These are probably unstoppable trends. The courts and legislators should strive for balance: preserving a place for reasonable and limited copyrights, while simultaneously abjuring extreme limits on society's ability to "remix" culture.

In the case of Grokster, the Supreme Court could do worse than look to its own 1984 decision in *Sony v. Universal Studios*. In that case, Universal charged that Sony's Betamax VCR encouraged copyright infringement. The Court let Sony off the hook, citing the VCR's "substantial noninfringing uses." The Court was right at the time. Let's hope the Grokster decision is just as far-seeing. ■



NANOTECH

Big Steps for Small Things

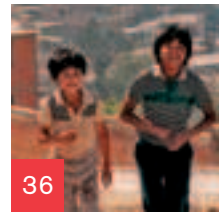
Now's the time to pick the winners

Five and a half years ago, in the still heady days of the technology boom, President Bill Clinton announced the National Nanotechnology Initiative. The federal program provided almost $500 million in funding for the fledgling field of nanotech in 2001. More importantly, it gave credibility to research that had all too often suffered from hyperbole. Since then, nanotech has had its share of awkward moments—such as the cancellation of a high-profile initial public offering (Nanosys)—and growing pains, including the enthusiastic embrace and subsequent skepticism of venture capitalists. But for those observers patient enough, there are numerous signs that nanotech is quietly moving into its next stage of development, a stage in which more and more promising research moves into commercial development.

Three of the nine deals featured in "Dealflow" on page 33 (a monthly column that tracks financing for innovative startups, "Dealflow" makes its debut in this issue of *Technology Review*) are from the generation of nanotech companies founded in 2000 and 2001. Nanomix, Nantero, and NanoOpto are notable not only for their strong academic credentials (the companies draw on research done at the University of California, Berkeley, Harvard University, and Princeton, respectively) but because of their progress toward commercial products. Take Nanomix; a *TR* profile of the company from September 2002 *(see "Nanotech by the Numbers")* described it as having impressive technology but still struggling to develop a convincing and viable business model. Three years later, Nanomix is introducing its first product line: chemical sensors based on carbon nanotubes, for use in medical and industrial applications.

Another encouraging sign for nanotech is illustrated in "Data Mine" *(p. 31)*. While annual federal funding for nanotech in the United States has roughly doubled since 2001, the vast majority of investment now comes from the private sector. The National Nanotechnology Initiative might have kick-started nanotech funding, but these days the business community is also fully committed. Even as nanotech's prospects turn more bullish, investors will be wise to adopt an attitude of patience. But for those interested in the long term, it's a great time to begin choosing the future winners. ■

COURTESY OF NANTERO



VACCINES

Market Injection

Nongovernmental organizations can meet a severe need in the market for vaccines: buyers

In January, GlaxoSmithKline (GSK) launched Rotarix, a rotavirus vaccine, in Mexico. That launch may alter the course of vaccine development for the better: Rotarix was the first vaccine from a major pharmaceutical firm to debut not in the United States or Europe but in a poor country. The story of Rotarix *(see "The Vaccine That Almost Wasn't," p. 36)* shows that getting vaccines where they are needed most requires giving companies like GSK financial incentives. The emergence of what can be thought of as a superbuyer for vaccines—the Global Alliance for Vaccines and Immunization (GAVI)—may help create those incentives.

Before GSK's Rotarix, the vaccine story usually went like this: A drug company would develop a vaccine for a European country or the United States. It would charge a relatively high price for about 15 years, then, once it had made a profit, and the medicine had gone off patent, it would introduce the vaccine at a lower price to poor countries. The trouble with this model is not just that 15 years is a long time to wait; it's also that certain diseases are much more dangerous in poor countries than in rich ones.

Rotavirus, which induces diarrhea, is one such disease. Although almost every child is exposed to it by the age of five, its horror is not universal. In the United States, it kills between 20 and 40 children per year; in the rest of the world, it kills an estimated half-million children (about 1,000 in Mexico alone).

Part of what made GSK alter its model was the emergence of GAVI, which was founded five years ago, thanks largely to $750 million from the Bill and Melinda Gates Foundation. In 2003, GAVI named rotavirus a top priority, and this January, the Gates Foundation pledged another $750 million to it over the next 10 years. GAVI's Vaccine Fund serves countries whose per-capita gross national income is less than $1,000. Though the fund will not directly benefit Mexico, whose average income levels are too high, it is poised to help fund vaccination in scores of countries. GAVI's buying power helped convince GSK to forgo the traditional road to vaccine development.

If all goes according to plan, GSK will introduce Rotarix to other Latin American countries, and Asia, by the end of the year. While it plans to target Europe and the United States later on, the developing world is its first priority. This is as it should be. Countries should support GAVI and programs like it so that drug developers like GSK have the financial incentive to meet the most urgent medical needs. ■

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Forward

Pixel Perfect 23
Design by DNA 24
America Out-Teched 26
Inst ant Networks 28
10 Years Ago in *Technology Review* 29

Voices

"We can't afford to back out now."
Beatrice De Vos, director of worldwide medical affairs at GSK Biologicals, on the development of an antidiarrhea vaccine, p. 38

It was Woodstock without the mud and squalor, and with a penguin in the middle of the room.
Stanford Law School's Lawrence Lessig on the free-software lab at the World Social Forum in Porto Alegre, Brazil, p. 53

"So long as we retain one trace of ethical discrimination, the use of great powers for base purposes will constitute the full moral equivalent of sorcery and simony."
Norbert Wiener, cybernetics founder, p. 82

"[A] Patriot battery on the battlefield can be very much alone."
The U.S. Defense Department's Defense Science Board, p. 40

INTERNET

Tagging Is It

Social bookmarking emerges as a wiser way to navigate the Web

WITHOUT GOOGLE, Yahoo, and their brethren, using the Web would be like wandering through a library where a prankster has restacked the books at random. Still, sorting through thousands or millions of pages spurted out by a search engine can be nearly as overwhelming. Imagine instead being able to call on the group judgment of other users, people who are constantly skimming the latest Web content and arranging the best stuff into neatly labeled piles.

It's called tagging, and it's going on at a handful of free websites—Delicious, Flickr, Furl, and Rojo, among others—where members are voluntarily classifying and categorizing thousands of pieces of content each day. The phenomenon is growing fast: Delicious alone had 90,000 total users by April 2005, up from 30,000 the previous December.

Taggers aren't acting unselfishly. The main point of these sites is to allow members to store the addresses of Web pages that interest them, which they can later revisit from



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any computer or browser. Along the way, they are invited to add tags to the pages they bookmark—descriptive terms of their own choosing that make it easier to find favorite sites in a big stack of bookmarks. But there's a twist that makes tagging a collectivist undertaking: everybody can see everybody else's tags. The ability to see what other people are tagging can lead you to material you might not discover on your own. "It represents a break in the traditional assumptions about how we know things," says David Weinberger, the author of *Small Pieces Loosely Joined: A Unified Theory of the Web* and the coauthor of *The Cluetrain Manifesto*, an e-commerce classic published in 2000. Tagging is "not a structure that's given to us. It's one that is created by the user."

"A bunch of people doing 'okay' tagging may actually have a higher net value than an authoritative organization telling you how information should be organized."

Tagging is already attracting the attention of the traditional search industry. In March, Yahoo acquired Flickr, a photo-sharing site where users can tag their own pictures and others'. Technorati, a site that tracks the most-discussed subjects on Web logs (or "blogs"), makes extensive use of tags from Delicious, Flickr, and Furl. Last September, Looksmart purchased Furl, and it is now adding the ability to create instant Furl bookmarks to its family of specialized search sites. "It makes a lot of sense to have a capability that allows for sharing of essential Web pages," says Debby Richman, Looksmart's senior vice president of consumer product development.

There's no uniformity to the way people tag Web pages, so the same tag might wind up being applied to very different kinds of content. But to most developers, that's actually a strength of the technology, not a weakness. "The information you get [through tags] is always going to be somewhat imperfect and fuzzy," says Joshua Schachter, the creator of Delicious. "But a bunch of people doing 'okay' tagging may actually have a higher net value than an authoritative organization telling you how information should be organized." **Wade Roush**

THEORY

In Silico Immunology

Melvin Cohn uses computers to clarify one of biology's most confusing fields

FOR MOST OF US, the jargon of modern immunology is incomprehensible. Even immunologists themselves frequently have trouble understanding their colleagues. So the plainspoken Melvin Cohn is a welcome island in a confusing sea of concepts like self/nonself, costimulatory signaling, and sorting the repertoire. And in fact, Cohn, who at 83 is still a fixture at the Salk Institute for Biological Studies in La Jolla, CA, has clarified his ideas to the point that he has come up with a list of discrete immunologic rules. Those rules allowed him to build a computerized version of the entire human immune system. "If you can't make it clear, you don't understand it yourself," says Cohn.



Melvin Cohn's theories explain why mice and men are equally protected from infection.

BRAD HINES (COHN); COURTESY OF THE OFFICE OF NAVAL RESEARCH (SHIFTY BLADES)

A microbiologist and biochemist by training, Cohn has spent more than half a century investigating the immune system. He views himself not as a theoretician but as a conceptualist, someone who tries to assemble many small theories into a comprehensible big picture. "The theoreticians largely came from physics and mathematics, and they didn't understand immunology," says Cohn, who leads the Conceptual Immunology Group at the Salk Institute. He is well known for elucidating provocative and fiercely debated concepts about the evolution of the immune system and how it operates. "Mel is the smartest, most thorough, most creative living immunologic theoretician," says Polly Matzinger, an immunologist at the National Institute of Allergy and Infectious Diseases.



One of Cohn's fundamental immunologic rules, which posits what he calls "protectons," now serves as the foundation for his computerized "synthetic immune system," whose roots stretch back to the early 1980s. In 1990, Cohn and longtime collaborator the late Rodney Langman proposed that, just as a brick wall is made of many uniform bricks, the immune system is built of many nearly identical protectons. Each protecton is a corps of about 10 million immune cells and various biochemicals that work together to protect the body from invaders. The bigger an animal, the researchers reasoned, the more protectons it has. The relatively small size of the protecton helped Cohn, Langman, and programmer James Mata deal with the enormous complexity of the immune system when they revamped their *in silico* model five years ago.

"A mouse has 10^8 [immune] cells, and a human has 10^{12}," says Cohn—meaning that a mouse has 10 protectons and a human has 100,000. Yet "a mouse is as protected as a human being," he says, because it has as many immune cells and biochemicals in each milliliter of its blood. "If you look at a hummingbird of one gram and an elephant of 10 tons, they're about equally protected from pathogens," says Cohn.

Available free online, the synthetic immune system still looks somewhat crude, and Cohn acknowledges that "it isn't user friendly enough," which he says explains why few people have played with it. Still, "it's a useful tool that takes what one thinks are the minimal rules of how the immune system works and lets you see what those rules generate," says Colin Anderson, an immunologist at the University of Alberta in Edmonton, Alberta, whose research focus is on preventing the immune system from attacking organ and cell transplants.

"Mel is the smartest, most thorough, most creative living immunologic theoretician," says one colleague. He's also one of the most controversial.

Cohn says the synthetic immune system allows researchers to test various assumptions that undergird their own models of how the real immune system works. He gives the example of a model of how the body defeats an infection that humans normally clear within days. "The computer says it takes a month to mount an effective immune response. Well, the individual would be dead in that time. So which one of these assumptions is causing the delay?"

The University of Alberta's Anderson says he imagines that as the system improves, it may be able to help answer questions like how to help the immune systems of people with diabetes better tolerate transplants of insulin-producing beta cells. But Cohn says he ultimately thinks the *in silico* immune system provides a valuable tool, regardless of whether it leads to practical ends. "Understanding has a value in itself, and I'm not going to tell you what use it is," he says.

For all his plain talk, Cohn has met his fair share of immunologists who don't have a clue what he's getting at—or, for that matter, why he has spent more than two decades developing a computerized version of the immune system. But he has learned to live with the doubters. Says Cohn, "I'm so immune to that." **Jon Cohen**

Prototype



An actuator torques a rotor blade to give a helicopter a boost.

Shifty Blades

Shape-shifting rotor blades could boost helicopters' flight ranges and payload capacities. Designed by researchers at the U.S. Office of Naval Research, the Naval Air Systems Command, and Boeing, a new "torsional actuator" twists a rotor blade along its length like someone trying to pop ice cubes out of tray. The angle of rotation is no greater than two degrees in either direction, but the resulting shape change can customize the blade's aerodynamics for either hovering or flying forward. Installed in the blade near the rotor hub, the actuator has a core made of NiTinol, a nickel-titanium alloy that deforms when subjected to an electric current. This deformation rotates a rod running through the blade; the rod in turn torques the blade. Calculations indicate that using such a blade instead of a fixed-shape blade could increase helicopters' payload capacities by 40 percent. The actuator project is scheduled to be completed in 2008, after which the device could be retrofitted into existing vehicles.

Pixel Perfect

Get too close to your TV screen, and you'll notice that each of its dots, or pixels, contains a trio of vertical stripes or "subpixels" colored red, green, and blue, with narrow black areas between them. This arrangement dates from the dawn of color television but has persisted into the age of advanced liquid-crystal-display computer

continued on p. 25



Ned Seeman uses DNA to make things no one has been able to make before.

DENNIS KLEIMAN

NANOTECH

Design by DNA

Ned Seeman's twist on manufacturing

DNA molecules provide the architecture for all living things. New York University chemist Ned Seeman thinks they could also be a perfect assembly platform for the smallest computing devices ever built.

How do you build things out of DNA?
We don't. DNA is just a way of organizing materials on a molecular level. It's scaffolding. For instance, carbon nanotubes—how are you going to organize them into a circuit? DNA gives you a way to arrange them into something useful. Because it has a very precise structure, and because you can control how other molecules associate with it, it's just punching a sequence into a machine. And because DNA self-assembles, if there are things attached to it—micro metallic particles or carbon nanotubes—those will self-assemble along with it.

DNA's a linear molecule. Why doesn't everything you make wind up being linear?
We use a synthetic form, which we program to give us branch points. Think of the double helix as two lanes of a highway; branched DNA corresponds to intersections. You can make molecules of pretty much any shape or size you want.

What kinds of things have you made?
Lots of crystals. The earliest complex device was something that changed its shape in a controlled fashion when you added a chemical. Last summer, we did a little walker that moved across a DNA "sidewalk." Each foot was tied down by a strand of DNA. We would rip off that strand, and then the foot was free to wander around, and then we'd put in another strand to tie it down and make the next step.

How does computing come in?
As things in the computer world keep getting smaller, they're reaching the point where top-down approaches—trying to make big things smaller—are hitting the wall. What we're doing is building from the bottom up—taking little things and make them bigger. And DNA lets you do true 3-D integration. There are issues of cooling and power loss that have to be addressed, but the point is that what we're doing is inherently three dimensional, which at the nano level is pretty amazing.

So is nanomanufacturing imminent?
We are probably not going to be using this approach to knit customized sweaters. DNA is expensive stuff; for now, at least, you wouldn't want to use it for large-scale anything. But 3-D configurations of atoms, or molecules, or nanoparticles—that has to have value, in terms of making things no one has been able to make before.

What about nanotech's skeptics?
Everything we're talking about is doable. Is it doable on a scale that's going to be worthwhile? No one knows. In 25 years we've taken something that was in my imagination to the point where we can take out patents and where there are now whole conferences devoted to the topic. **Spencer Reiss**

STARTUP

The Customer Is Always Right There

Reactrix Systems makes advertising an on-the-spot, interactive experience

COMPANY: Reactrix Systems

HEADQUARTERS: San Carlos, CA

AMOUNT INVESTED: $25 million

LEAD INVESTORS: Mobius Venture Capital, Worldview Technology Partners, Thomas Weisel Venture Partners

KEY FOUNDERS: Matt Bell, Jon Friedberg, Mike Schaiman

TECHNOLOGY: Software for interactive advertising

MATT BELL WAS a Stanford University undergraduate in 2001 when he started tinkering with what would become the basis for his company, Reactrix Systems. "I created this program for people to play with flames projected on a wall. I thought it might be good for raves," recalls the now 25-year-old Bell. The project might have retained its digital-toy status were it not for a trip Bell took to London that spring. "I saw ads projected onto the street," he says, "and thought, 'Wouldn't it be neat if I could "play" with the ad I just walked through?'"

So Bell decided to leave his job at Google and, along with fellow twenty-somethings Jon Friedberg and Mike Schaiman, raise $400,000 to launch Reactrix, a company specializing in "immersive interactive displays." By the end of 2002, the company had its first commercial deployment, an interactive floor at Toys R Us that let children chase the company's star-shaped logo; each time a kid stepped on a logo it would "pop" and transform into the store's mascot, Geoffrey the giraffe. This was soon followed by an installation at Las Vegas nightclub Tabu that let people dance with images projected onto tables.

Each installation includes an infrared camera, a computer, and a projector. As a person interacts with the projected image, the camera tracks his or her movements and feeds that information to the computer; the computer adjusts the image to make it appear to react to the person. Bell says the way in which the software processes information from the in-

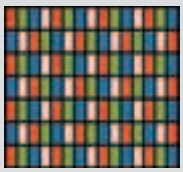


Reactrix is betting that customers will respond to ads that, like this one, respond to them.

COURTESY OF REACTRIX (CUSTOMER); COURTESY OF CLAIRVOYANTE (PIXEL)

Prototype continued from p. 23

monitors. A Cupertino, CA, startup called ClairVoyante thinks it's time to mix things up—and believes the result will be brighter, cheaper displays. Red, green, and blue together make white,





but to make a screen's whites even whiter, ClairVoyante's designers are adding a white subpixel to the mix *(top)*. At the same time, they're making each subpixel wider, so that a pair of subpixels will take up the same space as three conventional subpixels *(bottom)*. That means there's less black space overall; the combination of white subpixels and the new geometry almost doubles a screen's brightness. It also cuts manufacturing costs, since the design requires only two-thirds as many "source drivers," the electronic devices at the top edge of a screen that control each column of subpixels. ClairVoyante expects Asian manufacturers such as Samsung to launch the first "RGBW" devices—probably small-screen gadgets such as cell phones—in 2006.

Rear View Backbeat

Time may be running out for the bulky bass speakers on cars' rear window ledges now that the window itself can produce the same sounds. "We were researching active noise control when we discovered the window glass is an excellent membrane for generating low frequencies," says Urban Emborg, president of Sweden's A2 Acoustics. In fact, says Emborg, preliminary tests show that at very low frequencies glass could produce less distortion than premium subwoofers. In addition to boosting sound quality and freeing up trunk space, says Emborg, A2's glass-speaker system could ease vehicle assembly, since the glass and electronics can be preassembled as one unit.

continued on p. 27

frared camera enables the Reactrix system to operate in the dynamic environments of the real world, whereas earlier interactive projection systems could track users only against white backgrounds or in situations where the lighting conditions were tightly controlled.

Indeed, Reactrix is not the only company developing interactive displays. IBM's Everywhere Displays project makes use of mirrors and cameras to produce similar effects, while a system from Austin, TX–based artistic collective Mine-Control tracks people's shadows instead of the people themselves. But Reactrix's most direct competition may come from Toronto-based Gesturetek, which has created interactive floor displays for clients such as Coca-Cola and Krispy Kreme.

But where Gesturetek is focusing on selling or licensing its technology for a variety of applications, including gaming, virtual-reality-based rehabilitation, and museum kiosks, Reactrix aims instead to build and operate a global network of advertising installations. Linking each installation to the Internet would allow the company to upload new ads and track their usage statistics. Former Yahoo CEO Tim Koogle is a major investor in Reactrix and serves on its board of directors; he says the company would make the bulk of its money not by selling its technology, but from advertising revenue, which it would share with the venues that host its installations.

Whether the novelty of ads you can play with in real time is robust enough to sustain long-term business interest remains an open question.

In order to establish this new sort of advertising platform, Reactrix will have to line up both venue owners willing to install its system and advertisers interested in its form of brand messaging. It's already taken the first step: this January it began to install systems in AMC movie theaters as part of a 12-city deal. Norm Chait, a vice president of New York City–based MediaVest, a major media buyer, feels Reactrix's technology helps him get a particular kind of advertiser noticed. "The ones with the deeper pockets are the ones doing this," says Chait. "It's an add-on, a cherry-on-top kind of experience, because it's the kind of stuff that gets talked about." Reactrix is also finding interest outside the United States. In May, the company launched a partnership with South Korea's RK Media to install 20 systems throughout the country; LG and Hyundai agreed to advertise on the system.

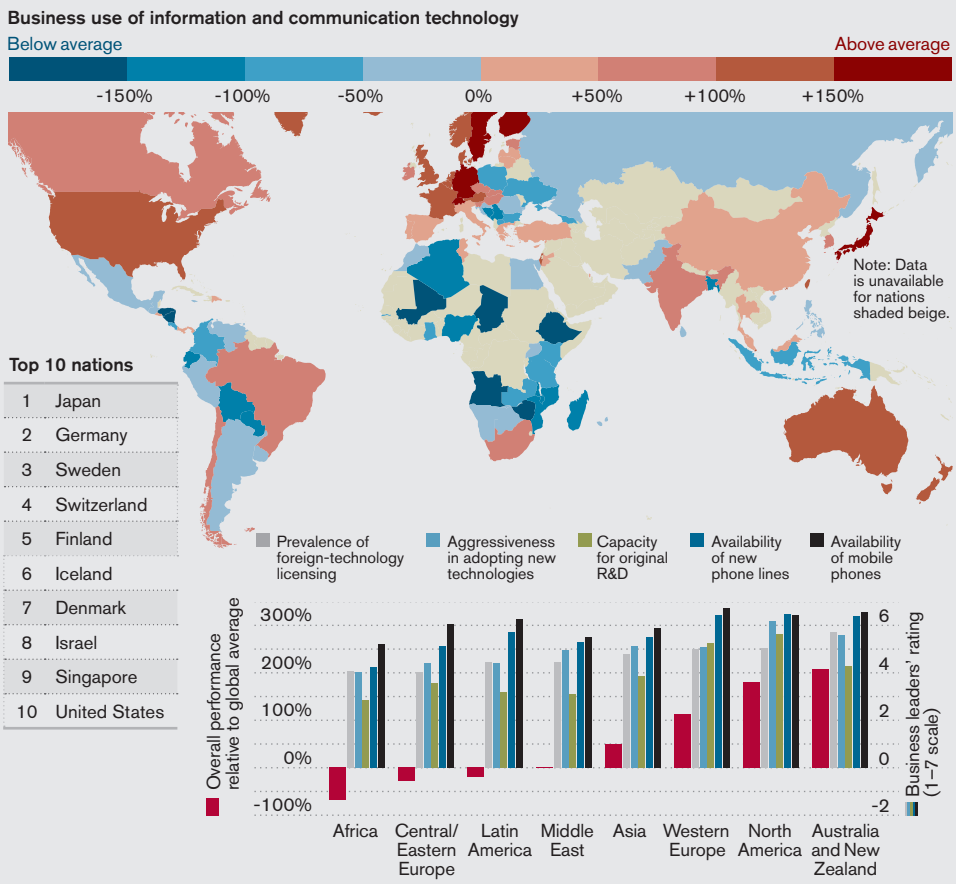
Whether the novelty of ads you can play with in real time is robust enough to sustain long-term business interest remains an open question. But with consumers increasingly resistant to traditional forms of advertising, Reactrix's technology has both retailers and advertisers intrigued enough to try to find out. **Todd Krieger**

BIOTECH

America Out-Teched

Despite the United States' reputation as a driver of innovation, in a World Economic Forum poll it ranked only 10th in the world in terms of business use of information and communications technologies. The WEF asked business leaders to rate their respective countries according to three criteria: how extensively companies take advantage of foreign technology licensing, how aggressively they adopt new technology, and how much original R&D they perform. It also asked the executives how readily their firms can obtain telephone lines and mobile phones, and combined all five ratings into one index score. Who does the WEF name the global leader? Japan. But as a whole, Asia does not perform as well as Western Europe, which boasts 6 of the top 10 nations.

SOURCE: WORLD ECONOMIC FORUM



BRAD HINES (AMEN); COURTESY OF CARAN (REAR VIEW)

MEDICINE

Shrinks: Picture This

California psychiatrist Daniel Amen uses SPECT—single-photon emission computed tomography—brain imaging to diagnose and treat attention deficit disorder and other behavioral problems. Many of his colleagues take a dim view.

What's the problem?
Psychiatry is the only field of medicine where it's considered normal practice to treat an organ—in this case, the brain—without looking at it.

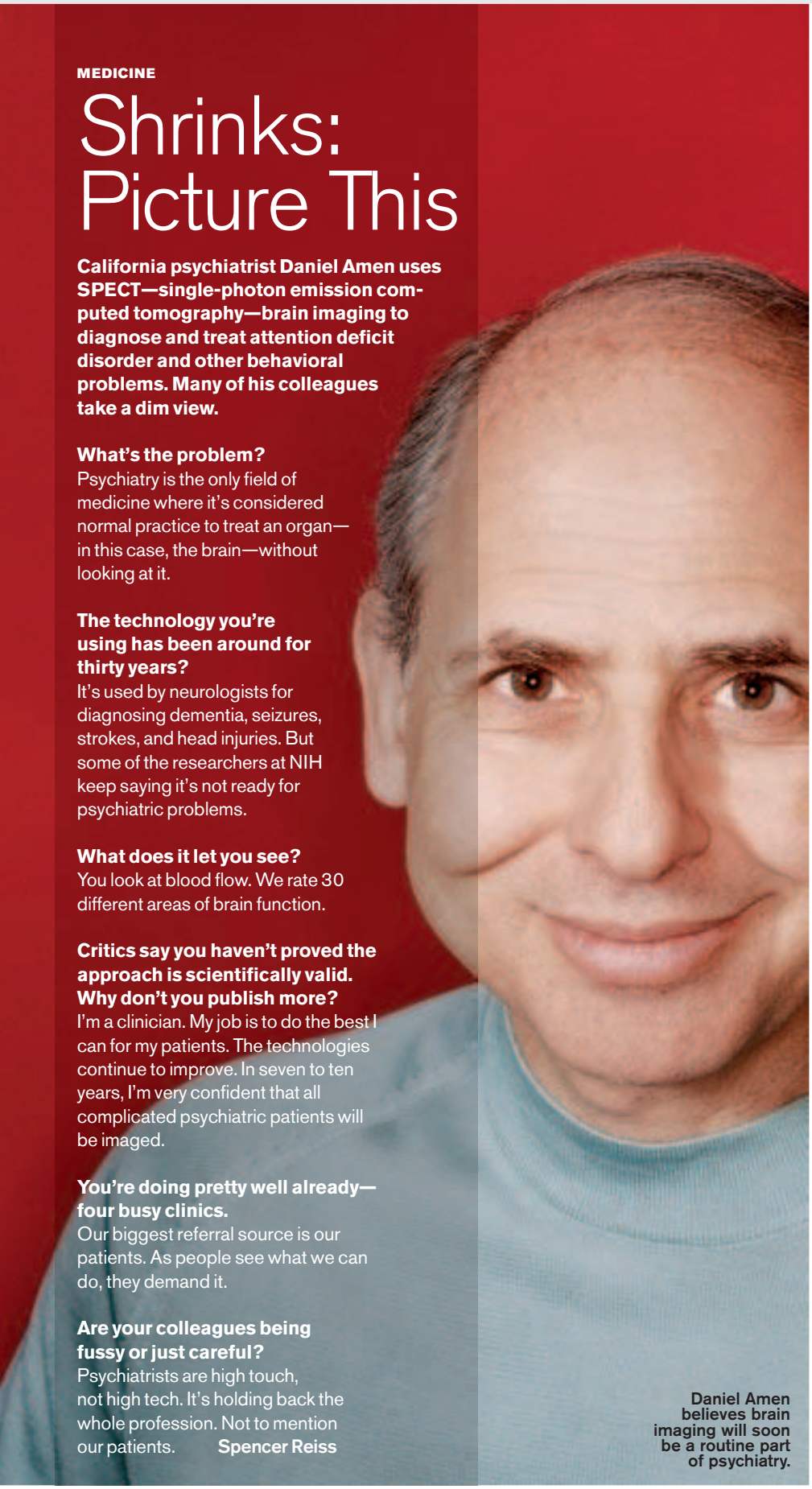
The technology you're using has been around for thirty years?
It's used by neurologists for diagnosing dementia, seizures, strokes, and head injuries. But some of the researchers at NIH keep saying it's not ready for psychiatric problems.

What does it let you see?
You look at blood flow. We rate 30 different areas of brain function.

Critics say you haven't proved the approach is scientifically valid. Why don't you publish more?
I'm a clinician. My job is to do the best I can for my patients. The technologies continue to improve. In seven to ten years, I'm very confident that all complicated psychiatric patients will be imaged.

You're doing pretty well already—four busy clinics.
Our biggest referral source is our patients. As people see what we can do, they demand it.

Are your colleagues being fussy or just careful?
Psychiatrists are high touch, not high tech. It's holding back the whole profession. Not to mention our patients. **Spencer Reiss**



Daniel Amen believes brain imaging will soon be a routine part of psychiatry.

Prototype continued from p. 25



The system sends signals from a car's audio amplifier to tubes 10 millimeters in diameter that lie along the bottom of the window frame. The tubes are made of a "piezoelectric" material that expands or contracts when a voltage is applied to it; the tubes create vibrations that propagate into the glass, producing deep notes that are audible in the vehicle but not outside. A2 is developing methods for mass-producing the technology.

Speed Reader

Ever wished you could speed-read? A new program called Jump could save you the bother. The software scans large documents and groups details about people, places, and other topics under descriptive headings, creating easy-to-navigate maps of the documents' content. And it's phenomenally fast, able to read more than 600 pages in 10 minutes. The idea is to let users get the gist of documents quickly and then find any specific information they want, says Nick Jakobi, head of linguistics research for Corpora, the Guildford, England, company that created the program. Unlike the "find" command in a word-processing program, Jump doesn't just search for strings of characters. It uses natural-language-processing techniques to break text into noun phrases and verb phrases and identify the subjects and objects of verbs. It can thus find not just mentions of a person's name, say, but other references to that person, even those that use job titles or pronouns. Corpora launched the program this spring as a tool for lawyers, journalists, and others in text-heavy professions.

STARTUP

Instant Networks: Just Add Software

PacketHop's technology helps emergency personnel link up on the fly

COMPANY: PacketHop

HEADQUARTERS: Belmont, CA

AMOUNT INVESTED: $15 million

LEAD INVESTORS: U.S. Venture Partners, Mayfield, ComVentures

KEY FOUNDERS: Michael Howse, Ambatipudi Sastry

TECHNOLOGY: Software that lets mobile devices form mesh networks

FOR COPS AND firefighters, being wireless isn't just about walkie-talkies anymore. An increasing number of emergency workers rely on high-speed wireless data networks while on the job. But many of these networks are set up in a hub-and-spoke configuration: if a hub, such as a wireless base station, goes down, the network fails. This summer, Belmont, CA's PacketHop will release software designed to prevent that type of failure. The software enables standard Wi-Fi-equipped laptops, PDAs, and other devices to form their own "mesh" networks and share video, photos, messages, and location data. With the technology, emergency workers at a disaster site can "set up a network on the fly without the need for infrastructure," says Michael Howse, the startup's president and CEO.

In a mesh network, each device operates as a node, capable of routing data to several other devices on the network—and the network survives even if several of its nodes fail or disappear. With PacketHop's software running on their portable devices, public-safety officials can, for example, view video streams from vehicle-mounted cameras. They can also instant-message each other, annotate or draw on images or maps in real time, and track each other's locations, provided that their mobile devices have GPS chips. The system can't handle voice data yet, so first responders who use it will still need handheld radios to talk to each other. But Howse says that, by providing an alternative means of communication, the mesh network should prevent the radios from getting overloaded during a major incident like a riot or a terrorist attack.



With mesh networking, emergency workers could share critical information during disasters like this oil company fire.

COURTESY OF PACKETHOP

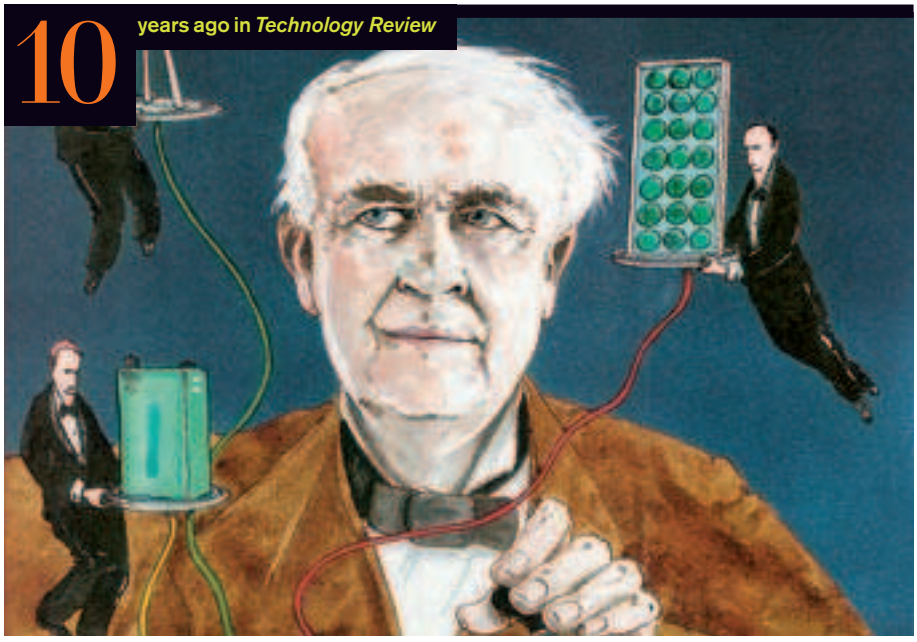
Menlo Park, CA–based nonprofit research institute SRI International spun out PacketHop in early 2003 to commercialize research that originated in a U.S. Department of Defense–funded project. The company has since secured $15 million in venture financing. PacketHop is now preparing to ship its products to several federal, state, and municipal law-enforcement and firefighting agencies.

Howse sees Motorola, which got into mesh networks late last year through the acquisition of a small company called MeshNetworks, as his main competitor. "Motorola has huge market presence and access to markets," says Peter Stanforth, formerly chief technology officer of MeshNetworks and now a vice president and director of technology at Motorola. "It would have taken us forever to get that."

Indeed, it will be a challenge for PacketHop to compete with a company that has such a long history of selling radios in the public-safety market. But because the startup's software works with any standard Wi-Fi-enabled device, its customers can shop around for the best prices in Wi-Fi hardware. This is very appealing to public-safety agencies spending tax dollars, says Glen Nash, the chair of the technology committee of the National Public Safety Telecommunications Council and a senior telecommunications engineer with the state of California. "It's important to be able to purchase equipment from multiple sources," says Nash. Motorola customers have to buy all of their mesh-networking equipment—hardware and software—from Motorola.

Nonetheless, both companies will have to work to convince public-safety officials to adopt mesh networking. "We're at the bottom of the learning curve" when it comes to new wireless technologies, says Nash, and the public-safety market is a cautious one. Nash, for one, is concerned about the security and reliability of mesh networks. PacketHop, however, hopes to show that reliability is precisely the advantage that its technology offers. **Corie Lok**

10 years ago in *Technology Review*



The Electricity Industry Sees the Light

Thomas Edison started the world's first electric power company in New York City in 1880. In a Wall Street warehouse, he connected a coal-fired boiler to a steam engine and dynamo, then linked the plant by underground wire to a block of nearby office buildings. When he flipped the switch, 158 light bulbs (also designed by Edison) flashed on, and the Edison Electric Illuminating Co. made converts of its carefully chosen first customers—J. P. Morgan and the New York *Times*.

Edison envisioned electricity as a competitive, service-oriented business with numerous suppliers. He would hardly recognize the vast monopolies that dominate the U.S. power industry today. Yet that very industry—long known for its fierce resistance to change—is now poised for a transformation that may bring it closer to Edison's original vision.

The winds of competition are roiling the power business. Since the early 1980s, a new breed of independent power companies has emerged to challenge protected utilities by building cleaner, more innovative, and more efficient plants. The Energy Policy Act of 1992 has heightened competition by giving these companies access to new markets. At the same time, miniaturized generators such as fuel cells and photovoltaics promise to transform the economies of scale that have shaped the industry, opening up a new era of decentralized power generation—perhaps even allowing individual homeowners to generate their own power. And new telecommunications technologies may link millions of these small generators and even household appliances into one "smart" power system.

Like the telecommunications industry of the early 1980s, the electricity industry is confronting increased competition and rapid technological change. These pressures could pave the way for a much more efficient and environmentally sound power system. But to get there, electric utilities will have to undergo a radical restructuring much like the one that transformed Ma Bell.

Christopher Flavin and Nicholas Lenssen (May/June 1995, p. 42)

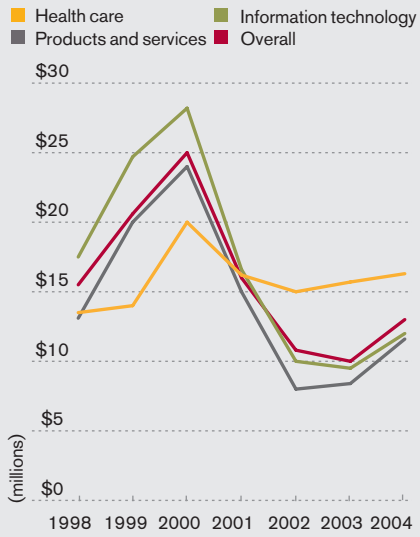
TECH FINANCE

Valuing Venture Capital Investments

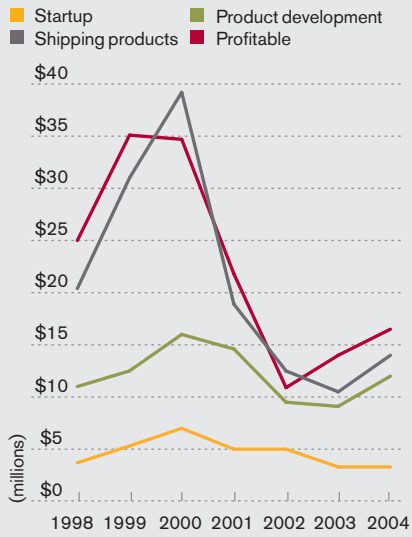
For the first time in five years, median valuations of companies receiving venture capital increased last year. Companies already shipping products showed the largest gains; in 2004, their median valuation was one-third higher than in 2003. Overall, though, valuations were still only about half of 2000's high. Health-care companies have suffered the least, their median valuation declining less than a fifth since 2000. But information technology companies have plummeted.

SOURCE: DOW JONES VENTUREONE

Median valuation by industry group



Median valuation by development stage



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Data Mine

Nanotech Grows Up

Nanotechnology research and development funding almost doubled to more than $10 billion in 2004 from the previous year. Most of the increase was driven by a big jump in corporate and private funding, which grew by 160 percent, while government and academic research outlays on nanotech R&D increased by a vigorous, but less outstanding, 37 percent. Japan led the way, with expenditures approaching $4 billion; the United States, however, was not far behind, with spending of about $3.4 billion.

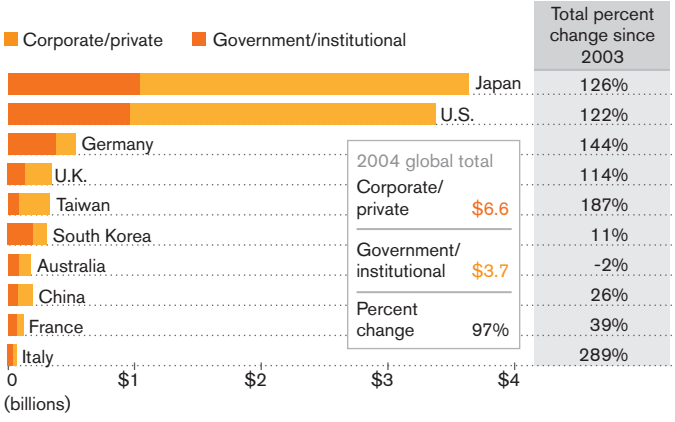
The expected payoff for all this investment could be huge, even over the next few years. Nanotech was already a $10 billion market last year, and that is expected to triple by 2008. Much of that growth will result from new nanomaterials. By 2008, more than $100 billion in products will likely involve some type of nanotechnology.

Still, only about half of Americans have heard anything about nanotechnology. Much has been made of the potential nanotech risks, from uncontrollable nanorobots to the breathing in of nanoparticles. Not surprisingly, public fears are directly correlated with the amount of knowledge that people have about nanotech: the less knowledge, the more fear.

Stacy Lawrence

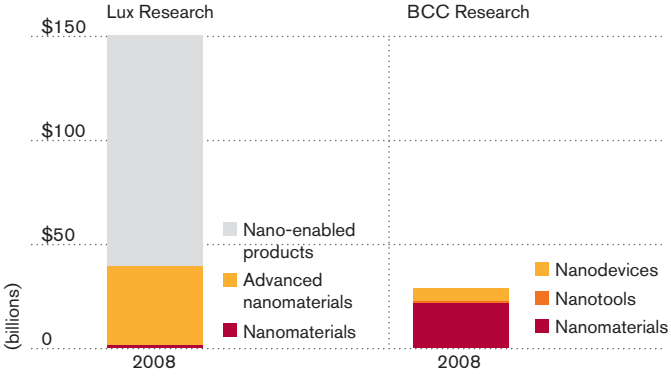
Global nanotechnology public and private R&D funding

More than $10 billion went into nanotech research last year. Two-thirds of this came from corporate and private funding, whose share was closer to one-half in the previous year.



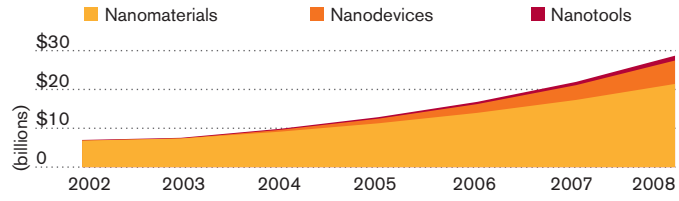
Projections for the global nanotechnology market

Predictions of the future growth of nanotech markets vary widely—as do the names used to define sectors of the industry.

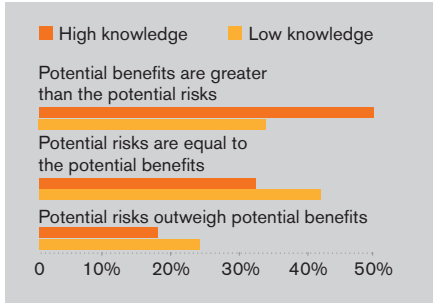


Global nanotechnology market segment projection*

Nanomaterials are likely to drive the near-term market.

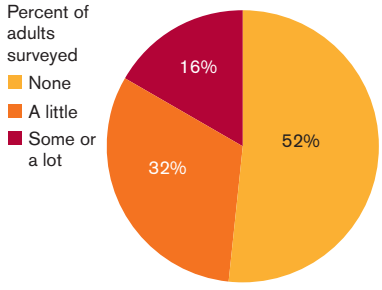


Perception of nanotech risks and benefits by respondent's knowledge**



In one survey, the more people knew about nanotech, the greater optimism they had about its potential benefits; the less knowledge, the more concern they had over potential risks.

American familiarity with nanotechnology**



More than half of Americans surveyed reported no familiarity with nanotechnology; a similar survey in the U.K. last year found less than a third of the public knew anything about nanotech.

*PROJECTION DATA BASED ON APPLICATION OF AVERAGE ANNUAL GROWTH RATE. **BASED ON A SURVEY OF 1,536 U.S. ADULTS, DATA FROM MARCH AND APRIL 2004.
SOURCE: VENTURE ANALYTICS, LUX RESEARCH, BCC RESEARCH, *JOURNAL OF NANOPARTICLE RESEARCH*, BMRB INTERNATIONAL

Funding of Innovative Startups

Company	Founded	CEO	Recent funding	Key investors	Technology	Prospects
Clearwire (Kirkland, WA)	2004	Craig McCaw	$100 million	Bell Canada and Intel Capital	Wireless broadband	**The CEO and the sums invested are reasons to take the startup seriously.**
TolerRx (Cambridge, MA)	2000	Douglas J. Ringler	$31 million in Series D financing	Bear Stearns Health Innoventures, Genentech, and Lehman Brothers Healthcare Fund	Drugs that keep the immune system from attacking the body's own tissues and proteins	**The latest cash buys time for products to mature, including two interesting drugs in human trials.**
TelASIC Communications (El Segundo, CA)	2002	Prabhat K. Dubey	$26 million in Series D financing	ComVentures, Agilent Technologies, and Redpoint Ventures	Analog and mixed-signal chips for third-generation (3G) wireless base stations	**A spinoff of Raytheon, the company has an impressive technology heritage.**
TopoTarget (Copenhagen, Denmark)	2000	Peter Buhl Jensen	$19.8 million in Series C financing	BankInvest, HealthCap, and Deutsche Venture Capital	Drugs that target the molecular mechanisms of cancers	**The company expects its most advanced drug to reach market in 2006: not long to wait.**
Evolva Biotech (Allschwil, Switzerland)	2004	Neil Goldsmith	$18 million in Series A financing	Novartis Venture Fund, Yamanouchi Venture Capital, APIDC-VC, and Symbion Capital	Using evolutionary processes to find new types of small-molecule drug compounds	**These are very early days, but at least venture capitalists say: we're impressed.**
Dilithium Networks (Petaluma, CA)	2001	Paul Zuber	$18 million in Series C financing	U.S. Venture Partners, Motorola Ventures, Deutsche Bank Capital Partners, and CM Capital	Hardware and software for telecommunications, with a focus on emerging 3G networks	**While 3G has so far fallen short of its promise, it could still take off. If so, the company might prosper.**
Nanomix (Emeryville, CA)	2000	David L. Macdonald	$16 million in Series C financing	Alta Partners, Sevin Rosen Funds, Star Ventures, and Harris and Harris	Nanoelectronic sensors based on carbon nanotubes for industrial and biomedical applications	**Nanomix is almost ready to introduce its first hydrogen sensors. Time to find customers!**
Nantero (Woburn, MA)	2001	Greg Schmergel	$15 million in Series C financing	Globespan Capital Partners, Charles River Ventures, Draper Fisher Jurvetson, Stata Venture Partners, and Harris and Harris	Nanoelectronic devices to replace existing forms of memory, including DRAM and flash memory	**Nantero's ambitions will take years to realize, but its innovative technology shows great promise.**
NanoOpto (Somerset, NJ)	2001	Barry Weinbaum	$12 million in Series C financing	First Analysis, Morgenthaler Ventures, the Draper Fisher Jurvetson network, and Harris and Harris	Nanofabrication methods for producing optical components	**NanoOpto now has products on the market and cash in hand. But building tiny parts is not easy.**

Company Spotlight

Clearwire As wireless-communications entrepreneurs go, few can claim more distinguished records than Craig McCaw. His biggest coup came in 1994, when he sold McCaw Cellular Communications to AT&T for $11.5 billion. Now, as CEO and chairman of Clearwire, McCaw is challenging cable and DSL service providers with wireless broadband service.

Last year, Clearwire bought NextNet Wireless, which supplies it with wireless equipment. Also last year, McCaw made a large investment in Microcell Telecommunications, a Montréal-based provider that could provide a foothold in the Canadian market. Currently, Clearwire offers its wireless broadband service in Daytona Beach, FL, Jacksonville, FL, Abilene, TX, and St. Cloud, MN.

The scope of McCaw's project is daunting. Not only is Clearwire acting as service provider, but it is also making hardware. And rollouts in relatively small cities might not prove to be the wisest strategy. Meanwhile, incumbent DSL and cable providers have spent millions to market their broadband services. Is Clearwire up to the challenge?

Nanomix When *Technology Review* profiled Nanomix in September 2002, the company was more of a promising R&D operation based on strong academic research and prestigious founders than a viable commercial concern. However, with a fresh $16 million infusion of cash, the company is now poised to introduce its first commercial products.

Nanomix plans to begin selling its nanotube-based sensors by the end of this year. The company has indicated that its first products will include hydrogen sensors, which typically detect explosive conditions, and a carbon dioxide sensor for respiratory monitoring.

To initiate the transition to its commercial phase, the company hired David Macdonald as CEO in March 2004. Previously, Macdonald was senior vice president for global operations at Nanogen, a San Diego, CA–based supplier of molecular-diagnostic-testing equipment.

Andrew Madden

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Pain Relief (for Some)

Biotech and pharma feel wonderful; Electronic Arts is having no fun.

If there is a single industry in our indices that needs pain relief, it is biotechnology and pharmaceuticals. With big pharma's business model deemed past its prime and biotech R&D progressing more slowly than the market had hoped, stocks in the sector have taken turns receiving poundings. Add to that the controversy over cox-2 inhibitors such as Merck's Vioxx and Pfizer's Celebrex, and investors could be forgiven for jumping ship. But the earnings engines inside nonpharma tech companies have been sputtering, reminding investors that whatever their faults, pharmaceutical companies still throw off a lot of cash. Thus, pharmaceutical and biotech stocks were back in action as first-quarter earnings started rolling in, accounting for four of the top six gainers in the *TR* Large-Cap 100 and the *TR* Small-Cap 50.

The *TR* Large-Cap 100 and Small-Cap 50 indices live online, where they are updated daily. Visit www.technologyreview.com/trindex.

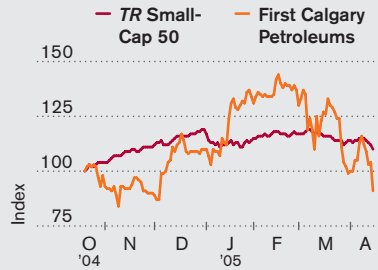
The losers' list featured more-traditional technology companies. Proving that it's not always fun to make games, Electronic Arts led the way down with a 25.8 percent drop through April 15 after cutting profit forecasts due to disappointing sales. EBay, which saw its stock fall 16.4 percent, is grappling with investors who can't seem to swallow the fact that hypergrowth can't last. (Not that all is lost: on April 20, eBay announced that first-quarter revenues climbed 36 percent over last year's, though it did confirm that growth is slowing in the U.S. and in the company's other established markets.) If CEO Meg Whitman wants advice on handling it all, she might want to call IBM's Sam Palmisano, who has seen his share of disappointing stock performance. His shares fell 16.2 percent during the period. **Duff McDonald**

TR stock index comparison



	% change 3/11–4/15	One-year % change
TR Large-Cap 100	-4.3%	1.9%
TR Small-Cap 50	-6.5%	8.7%
S&P 500	-4.8%	1.2%

In depth: First Calgary Petroleums



With oil prices in the mid-$50s per barrel, you might have thought that First Calgary Petroleums, an oil and gas exploration company, chose a great time to try to cash out. But as buyers balked at the tiny company's $2.5 billion market capitalization, short-sellers piled on. The stock fell 27.7 percent in the five weeks ending April 15. If only gasoline prices had done the same.

TR Large-Cap 100

	% change 3/11–4/15	Total market cap (millions)
Biotechnology and Pharmaceuticals	3.0%	$1,204,610
Media	-3.0%	$465,651
Health care	-3.5%	$205,122
Aerospace and defense	-3.8%	$224,600
Telecommunication services	-4.7%	$758,675
Energy	-7.3%	$1,214,218
Semiconductors and equipment	-9.7%	$356,722
Computers	-9.9%	$662,169
Software and services	-10.0%	$456,823
Consumer	-11.8%	$171,306

TR Small-Cap 50

	% change 3/11–4/15	Total market cap (millions)
Aerospace and defense	4.0%	$6,210
Biotechnology and pharmaceuticals	3.1%	$11,023
Semiconductors and equipment	0.0%	$7,552
Software and services	-1.9%	$15,187
Media	-5.0%	$12,041
Telecommunication services	-5.3%	$3,404
Health care	-6.0%	$9,603
Consumer	-9.8%	$2,807
Energy	-13.8%	$9,828
Computers	-14.2%	$15,564

TR Large-Cap 100, top gainers

	% change 3/11–4/15	One-year % change
Roche Holding (VTX: ROG)	9.7%	4.5%
Abbott Labs (NYSE: ABT)	9.0%	23.7%
Merck (NYSE: MRK)	8.2%	-22.9%

TR Small-Cap 50, top gainers

	% change 3/11–4/15	One-year % change
Protein Design Labs (Nasdaq: PDLI)	17.0%	-32.2%
Cree (Nasdaq: CREE)	11.3%	19.8%
Global Payments (NYSE: GPN)	8.9%	23.9%

TR Large-Cap 100, top losers

	% change 3/11–4/15	One-year % change
Electronic Arts (Nasdaq: ERTS)	-25.8%	-4.1%
eBay (Nasdaq: EBAY)	-16.4%	-14.6%
IBM (NYSE: IBM)	-16.2%	-16.2%

TR Small-Cap 50, top losers

	% change 3/11–4/15	One-year % change
Avocent (Nasdaq: AVCT)	-32.4%	-30.1%
First Calgary Petroleums (Toronto: FCP)	-27.7%	95.0%
FLIR Systems (Nasdaq: FLIR)	-26.6%	26.9%

NOTE: JAPANESE SEMICONDUCTOR EQUIPMENT MAKER IBIDEN HAS REPLACED VARCO INTERNATIONAL IN THE *TR* SMALL-CAP 50 AS A RESULT OF VARCO'S MERGER WITH NATIONAL OILWELL. SOURCES: STANDARD AND POOR'S CUSTOM INDEX SERVICES, *TECHNOLOGY REVIEW*, YAHOO FINANCE

The Vaccine That Almost Wasn't

THE CASE: GlaxoSmithKline wanted to make a vaccine for rotavirus, which, by inducing diarrhea, kills hundreds of thousands of children worldwide each year. In pursuing a winding path to develop Rotarix, the company may also have found a new model for bringing vaccines to poor countries.

In the fall of 1998, rotavirus, a leading cause of severe childhood diarrhea, seemed ready to go the way of measles and rubella, viral diseases largely defeated by the administration of childhood vaccines. Wyeth had just had its RotaShield vaccine approved by the U.S. Food and Drug Administration (FDA), and it was poised to begin hastening the virus's decline.

Rotavirus is a worldwide affliction: almost every child is exposed to it by age five. Every year in the United States, 50,000 people (mostly children) are hospitalized with rotavirus-induced diarrhea and dehydration, and between 20 and 40 die. In poor countries the picture is much more grim. Of two million deaths attributable to diarrhea worldwide each year, over half a million are caused by rotavirus. A successful rotavirus vaccine would make an enormous impact on world health.

In line behind Wyeth were SmithKline Beecham (now GlaxoSmithKline, or GSK) and Merck. Both companies had vaccine programs of their own and were eager to fight it out with Wyeth for the rights to a massive worldwide market. But a seemingly minor development in Wyeth's clinical trials portended trying times ahead. Five cases of intussusception occurred among the 10,000 recipients of the vaccine during clinical trials in the United States and Finland. Intussusception is a treatable but potentially fatal intestinal condition in which one section of the bowel slides into the next, like a collapsible telescope. The cases did not stop the FDA from approving the vaccine, but the potential side effect was noted in the vaccine's packaging insert.

For the next nine months, Wyeth's investment seemed to be paying off handsomely. At $38 a dose, with a three-dose regimen, RotaShield joined the U.S. schedule for routine childhood immunizations for 1999, and about one million infants received the vaccine. But by May 1999, 10 cases of intussusception were reported to the Vaccine Adverse Event Reporting System, which is jointly sponsored by the FDA and the U.S. Centers for Disease Control and Prevention (CDC). CDC officials looked into the matter, and an analysis turned up Wyeth's worst fear: rare cases of intussusception, estimated to be one in every 2,500 children vaccinated. (About a year later the best estimate was one in 10,000.) A rare enough side effect—but in a country where only 20 to 40 people will die each year from complications of rotavirus infection, the CDC deemed it an unacceptable risk. In July 1999, Wyeth suspended distribution of the vaccine. In October, a CDC advisory committee withdrew its recommendation that RotaShield be included in vaccination programs.



Mexico is the first developing country to be the site of a major vaccine's debut.

DARIO LOPEZ-MILLS/AP PHOTO

GlaxoSmithKline

2004 Revenues: $37 billion
Employees: 100,000
Annual R&D Budget: $5 billion

The finding prompted a crisis at GSK, which had a long-standing interest in a rotavirus vaccine, as well as a tradition of selling products to developing countries. The company had attempted to develop a rotavirus vaccine in the 1980s based on a bovine strain of rotavirus, but disappointing results prompted management to shift its R&D emphasis to an investment in a hepatitis E program. But Wyeth's apparent success with RotaShield led to renewed interest, and in 1997, GSK entered into an agreement with Avant Immunotherapeutics that secured the rights to market a vaccine initially developed by Richard Ward at the Cincinnati Children's Hospital Medical Center, based on a sample of a weakened human virus isolated from a Cincinnati child.

Like Wyeth, GSK had intended to introduce its vaccine (which would eventually be named Rotarix) to the U.S. market. But the intussusception problem represented a big hurdle. Rare side effects are extremely difficult to detect; to ensure that cases of intussusception either were not occurring or were mere coincidence, GSK would be required to conduct very large clinical trials. Before RotaShield, vaccine development did not routinely look for such rare side effects. Still, GSK had already invested millions in the rotavirus vaccine, and its managers did not want to give up so quickly, especially in light of the worldwide market for a vaccine.

When the CDC withdrew its recommendation for RotaShield in October 1999, GSK knew it was staring at a suddenly inflated cost for its own upcoming clinical trials. The company had already initiated discussions with the FDA about applying for approval, and it was finalizing the small-scale, phase I clinical trials intended to demonstrate the vaccine's safety. Those trials were far too small to show rare side effects like intussuscep-

tion. If ever there was a time to cut its losses, this was it—before the launch of costly, large-scale clinical trials. "We could have stopped easily," says Beatrice De Vos, director of worldwide medical affairs at GSK Biologicals, the Belgium-based subsidiary of GSK that handles Rotarix.

"We Were Quite Lucky"

But GSK found two reasons not to stop. First, the company determined that tests were unlikely to reveal a risk for intussusception, since its candidate vaccine was quite different from Wyeth's. Most significantly, GSK's vaccine was based on a human strain, while Wyeth's was a rhesus monkey rotavirus genetically engineered to carry surface proteins representing the human virus. GSK speculated that the nonhuman nature of the vaccine virus could be the source of the intussusception problem. "We started looking into the literature to try to figure out if there was any possible link between natural infection [with human rotavirus] and intussusception," says De Vos. "There was absolutely no evidence [of such a link]." That news helped convince upper management to carry on with the development.

The other advantage of GSK's vaccine was that it was much simpler than Wyeth's vaccine, because it targeted just one strain of rotavirus. Strains are defined by the chemical nature of key proteins that make up the outer shell of a virus. When a virus of a particular strain enters the human body, the immune system recognizes it and launches an antibody response. Four strains account for as much as 96 percent of rotavirus infections around the world. Wyeth's vaccine incorporated all four of those strains, which gave it a wider coverage of rotavirus as a whole than did GSK's vaccine, but which also came with safety drawbacks. Each incorporated strain requires an additional dose of virus during vaccine preparation, so that injection of a vaccine with four strains subjects a child to four times the amount of virus. It also makes potential safety problems more difficult to track down, because vaccine preparation is more complicated.

None of these matters was strongly considered when GSK first licensed its vaccine, because Wyeth's vaccine had already been approved and seemed well on its way to becoming a success. "We were quite lucky," says De Vos. But GSK's decision to target just one serotype with its vaccine was not without good reason. The single strain of rotavirus the company was targeting caused 75 percent of infections worldwide. And though Rotarix targeted only one set of surface proteins, clinical trials showed that the vaccine also conferred protection against other important strains. "This is a well-known phenomenon with viruses," says De Vos.

While GSK forged ahead with its preparation, it kept a close eye on events outside its walls. In February 2000, the World Health Organization (WHO) called a meeting to discuss the progress of rotavirus vaccines, including RotaShield, for developing countries. To the surprise of many, some health ministers at the meeting, upon consideration of evidence from Wyeth's clinical trials and the postmarketing studies, were disinclined to use RotaShield in their countries. De Vos believes the problem may have stemmed from the fact that a vaccine often elicits stronger immune responses from children in developed countries than in developing countries, possibly because of differences in nutrition. Wyeth conducted most of its clinical studies in the United States and Finland. Because of that, the health ministers from the developing world had no reliable information to approve the use of RotaShield in their own countries.

"[World Health Organization officials] did not want what happened with Wyeth's vaccine—where there was no data for the developing world—to happen again."

The WHO meeting was a further blow to RotaShield, but it represented an opportunity for GSK. WHO officials met with GSK soon after to ask the company to develop Rotarix for both developed and developing countries in parallel. "They did not want what happened with Wyeth's vaccine—where there was no data for the developing world—to happen again," says Deborah Myers, director of external and government affairs and public partnerships at GSK Biologicals. Such an expansion represented a much larger market than the United States and Europe, but it also would require expanded clinical trials and higher cost, and thus greater financial risk. The WHO's wish for a two-track vaccine launch also flew in the face of what De Vos calls "classical" vaccine development, where companies introduce a novel vaccine in developed countries at high prices, then sell the vaccine to underdeveloped countries at a reduced cost.

Introducing a vaccine simultaneously to developed and developing markets required GSK to adjust its thinking, but an outside development helped make the economics of bringing vaccines to poor countries more feasible. Nongovernmental organizations (NGOs) were becoming an increasingly potent economic force in the developing world. The Bill and Melinda Gates Foundation, for one, was beginning to make major contributions, especially to the Global Alliance for Vaccines and Immunizations (GAVI), a private–public sector partnership launched in 2000 to promote the widespread use of vaccines. That influx of money represented a boost to the existing NGOs and other buyers of vaccines in developing countries, such as government immunization programs and various countries' private sectors. (By December 2004, GAVI had disbursed over $532 million for vaccines, supplies, and support.) In 2003, GAVI announced that rotavirus was one of its two vaccine priorities, and seeded its Rotavirus Vaccine Program with $30 million.

Emboldened by the new buying power of NGOs, GSK completed phase II and phase III clinical trials to prove the vaccine's efficacy in Finland and several developing countries, including Brazil, Mexico, and Venezuela. Those trials were completely funded by GSK. The results were announced in October 2004. Rotarix was 85 percent effective in preventing severe rotavirus-induced diarrhea in Finland, and 86 percent effective in the Latin American countries. GSK is doing addi-

tional trials in South Africa and Bangladesh with support from the WHO, CDC, and other agencies to determine Rotarix's efficacy in these impoverished countries.

The positive results in Latin America gave Rotarix an apparently bright future in the developing world, but one more course adjustment was forthcoming. In a public meeting in September 2001, the National Vaccine Advisory Committee discussed the sample size that would be required to eliminate the possibility of a risk of intussusception. After the meeting and some internal discussion, GSK management decided to turn the entire classical vaccine development paradigm on its head, dropping its plan to do parallel introductions in the United States and developing countries, and focus solely on the latter. The company wouldn't elaborate on what was said at the FDA meeting, but GSK still plans to do a U.S. introduction after it proceeds in developing countries and Europe, which it hopes will approve a Rotarix license by early 2006. GSK also hopes that clinical trials in developing countries will eventually help convince the FDA of the vaccine's safety.

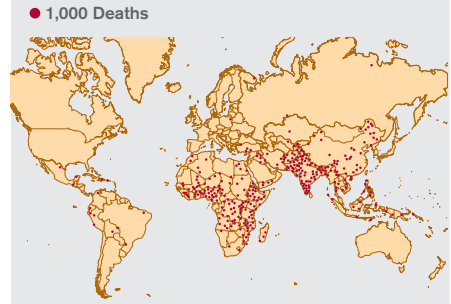
Getting to Market

In July 2004, Rotarix was approved for use in Mexico, where one in 50 children is hospitalized for rotavirus infection, and GSK introduced the vaccine to private markets in the country in January 2005. It began by supplying the vaccines to pediatricians. Though the company won't reveal sales figures, they are "in line" with expectations, says Pierrick Rollet, director of life cycle management. The company also expects the Mexican government to decide soon to include the vaccine in its general vaccine protocol. After Mexico, GSK plans to introduce the vaccine to other countries in Latin America as well as Asia this year and next. In the meantime, it is already licensed in the Dominican Republic and Kuwait, and GSK is in the process of obtaining licenses for it in 25 other countries, according to Myers.

In pursuit of opening up the widest possible market for Rotarix, the company is doing a complex dance with international agencies and national health authorities. GSK's chief goal is to get GAVI to approve Rotarix for funding. But to do that, GSK must first get the blessing of the WHO, because that is a prerequisite for UNICEF to buy the vaccine, and UNICEF is the procurement organization for GAVI. Once GAVI approves the vaccine, individual countries can make a request to receive funding for vaccine purchase. Even then, the vaccine must be approved for use by each country. If the process sounds complicated, that's because it is. "This is the first vaccine [not previously approved for use in developed countries] that GAVI will be considering for eligibility of funding. They're trying to decide what the process is. We're waiting for instructions on how to proceed," says Myers.

Global Distribution of Annual Childhood Deaths from Rotavirus

Of an estimated half-million annual deaths in children caused by rotavirus, almost all are heavily concentrated in poor regions of Africa and Asia.



SOURCE: EMERGING INFECTIOUS DISEASES

While it waits on those commitments, GSK plans to introduce the vaccine to private markets. Regardless of the outcome of negotiations with GAVI and others, GSK is deeply committed to Rotarix. "We can't afford to back out now. I think the bulk of the investment is done," says De Vos. Indeed, GSK recently completed a 450-million-euro (about $550 million) manufacturing facility in Belgium that primarily produces Rotarix.

GSK is not alone in its quest. Merck continued developing its rotavirus vaccine when RotaShield was withdrawn from the U.S. market in July 1999. Based on a bovine rotavirus that, like RotaShield, is engineered to include surface proteins from predominant human rotavirus strains, Merck's vaccine has done well in trials in the United States and Finland. Merck hopes to introduce it to the United States and Europe in this year or next.

The ultimate success of Rotarix remains to be seen, but Myers sees it as a model for GSK's future and the future of the vaccine industry. The launch has also taught GSK lessons about how best to bring a vaccine to market in the developing world. For starters, Myers believes there was insufficient public education in preparation for the vaccine's introduction. "Most mothers understand that their children have diarrhea, but they don't know about rotavirus and the impact that the virus can have on the health of their child," she says. In hindsight, GSK also would have started the prequalification process with the WHO sooner—before seeking licenses in individual countries—to prevent a holdup after licenses were granted.

An Emerging Model for Pharma

GSK has more than 25 products in its pipeline, a third of which are for diseases that are serious problems in the developing world, says Myers. One is a malaria vaccine, which completed phase II proof-of-concept trials in Mozambique in October 2004. The company is doing trials to see how well it works when administered with other vaccines to children younger than one, who are most susceptible. GSK hopes to enter the critical phase III trials at the end of 2006 or beginning of 2007, which if successful would put the vaccine in the developing world in 2009 at the earliest. The company can't say for sure what the strategy for introducing the malaria vaccine will be, however, because it is developing the vaccine with partners.

Still, Myers expects the Rotarix experience to be repeated at GSK: "We've made it clear that this strategy is not just a one-off." That could be good news for poor countries. The traditional model of developing a drug or vaccine and recouping costs in the developed world before introducing it farther afield leaves most of the world's population in peril. Myers expects other companies to follow GSK's lead in introducing vaccines and drugs quickly to neglected areas. "It's something that's going to be needed, and we need to figure out the issues and hurdles that need to be overcome in order to get vaccines as quickly as possible to the people that need them," she says.

Jim Kling

Preventing "Fratricide"

THE CASE: Despite a $3 billion upgrade, Raytheon's Patriot missile system shot down two coalition planes during the Iraq War in 2003. The troubled story of the Patriot should make defense contractors more wary of how militaries implement weapons systems—and militaries more wary of relying too much on software and automation.

In late March and early April of 2003, tragedy struck in the skies over Iraq. As the U.S.-led coalition marched toward Baghdad, two jet fighters—a British Royal Air Force Tornado and a U.S. Navy F/A-18—were shot down, killing two British crew members, Lt. Kevin Main and Lt. David Williams, and a navy airman, Lt. Nathan White. These deaths weren't caused by Saddam Hussein's purported arsenal of missiles, or even by antiaircraft fire, but by U.S. Patriot missile systems—built by Waltham, MA, defense contractor Raytheon and operated by the U.S. Army—that had erroneously identified the friendly planes as enemy missiles. In a third incident, a U.S. jet fired on a Patriot radar unit that the jet believed was an enemy surface-to-air missile system. Luckily, this incident caused no injury in the air or on the ground.

For Raytheon and the army, it was déjà vu with a deadly ending. During the Gulf War, the army claimed that Patriots were regularly shooting Iraqi Scud missiles out of the sky. In 1991, President George H. W. Bush even told cheering Raytheon employees that "Patriot is proof positive that missile defense works." Bush added that the system had shot down 41 of 42 Scuds. An investigation by a U.S. Congressional panel, however, concluded in 1992 that Patriots downed no more than four out of 47 Scuds—less than 9 percent—and added that "the public and the Congress were misled" by Raytheon and the first Bush administration.

Between the Gulf War and the Iraq War, the Pentagon pumped some $3 billion into improving and expanding the Patriot system. It is, after all, the most advanced system in the world for countering threats from the air, including attack planes and a wide variety of missiles owned by more than two dozen nations. The Pentagon investment was intended to buy improvements to software and guidance systems, as well as an additional type of "interceptor" (read "missile") built by a subcontractor, Lockheed Martin. The new interceptor, known as PAC-3, is designed to directly strike and destroy its target, whereas the older model, PAC-2, was designed to explode near it. A PAC-2 killed the British crew, and a pair of PAC-3s killed White.



A Patriot missile is fired during a 2001 military exercise in southern Israel.

AP PHOTO

Raytheon

2004 Revenues: $20.2 billion
Employees: 80,000 worldwide
Headquarters: Waltham, MA

Beyond assuring the safety of friendly troops and civilians, Raytheon has a great deal at stake in showing that the Patriot missile system can work reliably. It sells the system to Germany, Saudi Arabia, Kuwait, the Netherlands, Greece, Japan, Israel, and Taiwan in addition to the United States. And missile defense systems including Patriot are a core part of Raytheon's Tewksbury, MA–based Integrated Defense Systems business, which had 2004 net sales of $3.5 billion.

Given the extensive Pentagon investment in upgrading the Patriot system in the 1990s and early 2000s, there was reason to believe that the Patriot was reliable. But disaster struck anyway. The events of those two tragic days in 2003 reveal three dangers that can lurk in any advanced weapons program. First, there can be purely technological problems with the system itself. Second, there can be problems—both human and technological—with how the system is used in the field. Finally, neither corporations nor militaries are generally known for their willingness to confess errors and bring serious problems to light.

Putting the Pieces Together

A Patriot battery has three basic pieces, all portable: launch platforms containing Patriot interceptor missiles, a radar station that scans the skies, and a manned control station. But its information systems are immensely complex. As its radar tracks objects in the air, the system's computers calculate the objects' altitudes, speeds, and trajectories to identify planes as friendly or hostile, and even to discriminate among various types of missiles and identify where they will land.

At the control station, the computers' conclusions are displayed as a variety of icons on a screen. The system also exchanges coded signals with friendly planes that effectively demand, "Identify: friend or foe" (these are known as IFF codes). Each interceptor carries its own radar and guidance system; as it rockets skyward at supersonic speed, it tracks its target and adjusts its course as necessary.

So what went wrong in 2003? In the most recent official postmortem, in January, the Defense Science Board—an investigative task force appointed by the U.S. Department of Defense—gave some summary answers. While concluding that the Patriot was a "substantial success" because it had shot down eight Iraqi missiles and possibly a ninth, it also offered three criticisms. First, it suggested that the Patriot system was overdeployed, which was the logical result of flawed intelligence about the strength of Hussein's military. U.S. forces deployed 40 Patriot batteries, and coalition nations contributed another 22 batteries. This problem was magnified by another: the 40 U.S. batteries were set to function with a high degree of automation, paving the way for identification errors to produce fatal results. "The operating protocol was largely automatic, and the operators were trained to trust the system's software...a design that would be needed for heavy missile attacks," the task force wrote.

The second problem, said the board, was a communications failure. For one thing, the IFF system "performed very poorly." But more significantly, the Patriot batteries had little or no contact with other military systems, such as the radar planes known as AWACS, which were tracking friendly planes and, in theory, could have told the Patriot batteries to hold their fire. "We tend to assume that data are routinely communicated from one system to the other," the task force wrote. "The Task Force believes that we are a long way from that vision....[A] Patriot battery on the battlefield can be very much alone."

But the Patriot itself was also fraught with problems, the board concluded. "The third shortfall was the Patriot system operating philosophy, protocols, displays, and software....The solution here will be more operator involvement and control in the functioning of a Patriot battery, which will necessitate changes in software, displays, and training." But what does this mean, exactly?

"The unclassified stuff is pretty vague," says John Pike, director of Globalsecurity.org, a Washington think tank. Raytheon and members of the Defense Science Board declined interviews for this story; the army and U.S. Central Command (the joint body that had overall command during the war) did not comment beyond their official reports. In a statement, the army said it was already repairing problems with the Patriot. "These corrective actions include combinations of hardware modifications, software changes, and updates to tactics, techniques, and procedures," it says.

More-detailed explanations are left to experts such as Theodore Postol, professor of science, technology, and national security policy at MIT, whose analyses more than a decade ago were the first to expose the Patriot's poor performance in the Gulf War. Postol postulates that part of the problem with the Patriots that shot down the friendly planes in 2003 was electronic interference from nearby batteries. Each battery was aiming radar beams at the sky and calculating the altitude and range of airborne objects based on radar "returns." But because of their close proximity to each other, some batteries might have picked up radar signals originally sent by other batteries.

The result might have been the generation of false targets, and the correlation of those false targets with actual aircraft in the vicinity. The Patriot crews would then conclude they were looking not at a friendly plane but rather at a missile. Pike says the army failed to anticipate how multiple batteries could create such conflicts. "When [the U.S. Army] got into combat, they employed it in ways they had not trained for in peacetime. They had never planned on having this many Patriot batteries operating together in such close proximity with other radars," he says. The second obvious technological problem, in Postol's view, was the homing device in the Patriot interceptor itself. Once a missile was launched, it should have been searching for targets only in a limited area. But two of the missiles that targeted friendly planes made significant course corrections in order to reach the jets, he says. "So there is something wrong with the lock-on and homing of the missile," Postol says, "because in two cases they locked on to targets that were on trajectories far different than the targets they thought they were shooting at."

Philip Coyle, who during the Clinton administration was an assistant secretary of defense and director of operational test and evaluation, is now senior advisor to the Center for Defense Information, a think tank in Washington, DC. He believes that the Patriot's Achilles' heel is clearly its software. "One of the lessons is that the devil is in the details with respect to software," he says. "You really have to understand how these computers and software work—and I don't think that Raytheon has [done so]." He adds that, since military equipment grows more networked and automated every year, and thus more dependent on software, solving the Patriot's problems could be crucial to the future of warfare.

While Raytheon would not provide interviews about the Patriot's misidentification of friendly planes, in an e-mail, company spokesman Guy Shields emphasized problems outside Raytheon's walls. "Two of the main shortfalls seen in [2003] transcend just the Patriot; they involve combat identification and situational awareness," he wrote, citing the Defense Science Board report. "The Army has taken action, but only they can talk about it," Shields added.

To Postol, though, what's lacking is a critical examination of the continual failures that dog the Patriot program. "If the organization doesn't set a goal of identifying and fixing problems, they don't get fixed," Postol says. But if he's right about what happened in 2003, fixing problems with automated weapons systems will require more than openness. It will require those who design and implement the systems to worry more about what can go wrong in a combat zone. **David Talbot**

Pentagon Spending

In recent years, the Pentagon has spent billions of dollars developing and procuring the Patriot missile system. (Foreign countries are also major customers; Forecast International projects global sales of between 400 and 500 missiles annually over the next few years.)



*DEPARTMENT OF DEFENSE BUDGET REQUEST. ALL AMOUNTS ARE FOR FISCAL YEARS.

SOURCE: DEPARTMENT OF DEFENSE

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Brown Goes Bluetooth

THE DECISION: United Parcel Service wanted to track packages more efficiently. But instead of switching from bar codes to radio tags, it poured $120 million into a groundbreaking mix of Bluetooth and Wi-Fi technology.

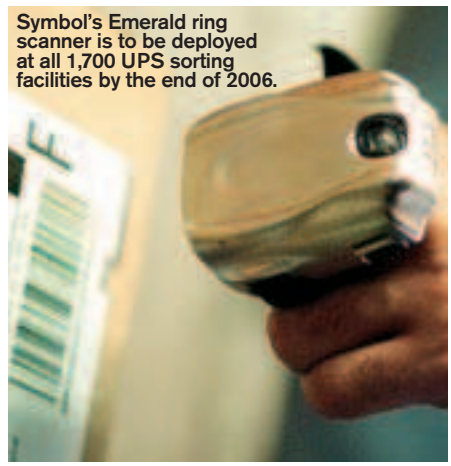
UNITED PARCEL SERVICE, THE $36.6 billion Atlanta-based shipping behemoth, has 55,000 sorting workers at 1,700 worldwide facilities. Their Herculean task is to scan—by hand—the bar codes on 14.1 million parcels every day so that UPS and its customers know where those parcels are at all times. Beginning in 1996, UPS sorters began using a scanner worn like a ring and linked by a cable to a forearm-mounted terminal, which wirelessly transmitted bar code data to a facility's server.

The devices gave UPS almost-real-time package tracking—something its customers were beginning to demand. But they also led to millions of dollars in unforeseen outlays. "You can imagine the issues we ran into," says John P. Killeen, director of global network services at UPS. "The cables would get caught on the packages or get yanked out, and once they were disconnected, productivity stopped." UPS needed to buy and store spare wires and other equipment for hundreds of worldwide facilities, and maintenance workers were kept constantly busy fixing scanners.

So in 2001, UPS put out a call for bids for a wireless scanning system. Symbol Technologies, a Holtsville, NY–based company that makes laser scanners and builds wireless networks for companies such as Kraft Foods, Nestlé, and DHL, won the bid. Symbol convinced UPS to test a new device that used Bluetooth's short-range radio capability to relay a parcel's bar code information from a worker's ring scanner to a wireless receiver mounted on the worker's hip.

After an initial testing phase in 2002, Killeen says, UPS found that Symbol's Bluetooth-equipped Emerald ring scanner, paired with the belt-worn Windows CE-based terminal, could handle shipping data at up to 60 scans per minute, double the rate UPS was getting with the hardwired scanners. In part, the speed increased because Symbol's belt terminal transmitted a package's tracking data to a shipping facility's server using the freshly available 802.11b wireless standard.

The Emerald scanners and terminals, in fact, represented the first viable combination of Bluetooth and 802.11b technology in one system, a combination made difficult by the fact that both technologies send signals across the 2.4-gigahertz radio frequency. Another difficulty was that in shipping facilities, sorters—and thus their electronic devices—work in close proximity to each other. Symbol therefore had to equip its scanners and terminals with software designed to prevent the "collision of information packets," Killeen says.



Symbol's Emerald ring scanner is to be deployed at all 1,700 UPS sorting facilities by the end of 2006.

United Parcel Service

2004 Revenues: $36.6 billion
Employees: 384,000
Daily Online Tracking Requests: 10 million

Test results convinced UPS's information technology division to push for implementation of the scanners. This meant asking senior management to make a $120 million investment in a three-year equipment rollout. Once UPS's executive steering committee approved the plan, 55,000 of Symbol's machines were ordered. Deployment started in July 2003 and is to be finished by the end of 2006.

According to David Salzman, a program manager for information services at UPS, the new equipment will pay for itself within 16 months of full deployment. About a third of the savings will come from increased productivity; the remainder will come from reductions in equipment repair costs and spare-equipment purchases.

Donald B. Rosenfield, director of the Leaders for Manufacturing Fellows Program at MIT's Sloan School of Management, likes UPS's move but wonders whether the company considered using radio frequency identification (RFID) instead of Symbol's scanners. RFID tags transmit package data automatically to readers mounted at shipping centers, eliminating the need for manual sorting. Robert Nonneman, a manager of industrial engineering at UPS, says the company has watched RFID for 15 years but doesn't see it as an imminent solution to the problem of parcel tracking. In test runs, he says, RFID tags did not surpass the accuracy rate of bar code scanners. And an RFID rollout—including tags and a new technological infrastructure—would be costly. "You can't simply replace optical scanners with an RFID reader and expect an improved return on investment," he says. "There have to be process changes to leverage the technology."

So far, 25,000 Symbol devices are in place at 400 UPS sites. "We've created one of the world's largest wireless LANs," Killeen says. He adds that Bluetooth and Wi-Fi connectivity are also being incorporated into the handheld computers carried by UPS drivers. The new electronic clipboards, first deployed in April, allow a driver to receive last-minute delivery or route changes via a truck's receiver. Previously, updates came from putting the clipboard in a cradle inside the truck.

A modest technological improvement can deliver nicely. UPS has received a good thing in a small package. **Tom Mashberg**

COURTESY OF UNITED PARCEL SERVICE

Good-Bye to Venture Capital

Technology finance has turned rational—so I'm outta here.



Howard Anderson is the William Porter Distinguished Lecturer at MIT's Sloan School of Management, where he teaches courses on early-stage companies. He founded the Yankee Group and cofounded YankeeTek Ventures and Battery Ventures. He plans to raise no new monies for his venture funds.

GOOD-BYE! We venture capitalists like to think of ourselves as giants striding across the technology landscape, showering money on terrific young entrepreneurs, adding value, creating jobs, nurturing real companies. We are financial samurai. But I am giving it up. Why?

First, technology supply is bloated. Innovation is not dead, but demand for new technologies is moribund and will continue to be weak for at least the next five years. During the boom times, VCs financed more than 5,000 new companies a year in information technology, communications, biotechnology, and the Internet. The problem is that the buyers of new technology cannot possibly utilize all this stuff. There is a very real limit to what can usefully be deployed. IT and communications spending is no longer growing at 15 percent per year; growth will be in the middle single digits for at least the next five years. Therefore, few software and communications companies will enjoy the double-digit growth that inflames company valuations and makes VCs rich.

Second, there's a good reason why technology spending is stagnant. The hype machine is broken. For years, technologists told the world that "information is strategic"; we said that if companies didn't overspend to protect against Y2K they were committing corporate hara-kiri. Executives spent like crazy people. No longer. Their new mantra: spend no more than last year.

Third, the financial markets for technology companies are no longer exuberantly irrational. VCs *hate* rational markets: rational markets value companies at two and a half times their sales at an initial public offering or one and a half times their sales at a merger. We need a little irrationality to earn a living—but the total capitalization for the leading technology companies is now one-sixth of what it was five years ago.

Fourth, these changes in venture funding are structural, not cyclical. VCs actually *like* cyclical markets; we can buy in cheaply and wait for exuberance to bail us out. Traditionally, we knew that if we picked the right sector we could make 10 times our money. In fact, we knew if we picked the best two or three companies in that sector, we could make 50 times our money—but you get my point. But those days are, regrettably, over.

Here's why: it takes about $30 million to get a startup software company to break even—and even great software companies rarely grow more than 100 percent a year. In irrational times, a software company with $30 million in sales would have been worth $180 million, or 600 percent of a VC's investment. Which is good, but not great. Unfortunately, in rational times, the company would be worth $47 million to the investors, or only 157 percent of their investment. *But that's over five years!* Per year, it's a return of only 11 percent—and that's for a winner. Remember: in venture funds, only 20 percent of investments are winners. Forty percent are in the middle, 20 percent are losers, and another 20 percent are write-offs.

Venture funds all strive to rank in the top quartile. But the returns of the top-quartile funds depend on when they were launched. Take a look at these numbers for venture capital returns from Cambridge Associates:

Year	*Percentage increase*
1984	12.9
1988	22.7
1994	49.6
1997	67.5
1999	–8.7
2000	–8.3

If you were a VC between 1994 and 1997, you couldn't help but make money. But by 2000, you were underwater.

Finally, it's not just supply of new technology that is too abundant. Ten years ago there were 240 member firms in the National Venture Capital Association. Today, that membership has nearly doubled, and our fund size under management has increased eightfold. There's too much venture money pursuing too many deals. There's nowhere for all that money to go: we can't spend the money we've raised.

Venture capitalists view themselves as pragmatists, but if they think the dynamics of the business haven't changed, they're as self-deluding as the next person.

Ever wonder what we did for a living in early-stage venture funding? I bet you think we spent the day searching for the next insanely great company. But we spent most of our lives in endless meetings with people who were lying to us: scientists who swore that their patents were solid and entrepreneurs who insisted that they had no competition. We lied right back at them: said our money was different.

That was the old way, and it was tons of fun, and we all made too much money. I'll miss it. But now the markets are too rational, and the returns are too small and uncertain. So, time to leave. ■

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The People Own Ideas!

New technologies are forcing us to make important choices about how we use books, music, software, and other cultural products. Do we want them to be free—or not?

By Lawrence Lessig Illustration by John Ritter





We entered the youth camp that morning by passing down a long, white gravel road and under a wooden gate. Spread to one side, and for as far as you could see, were rows and rows of tents. In front were scores of showers, with hundreds of kids in swimsuits milling about, waiting to rinse. It felt like a refugee camp.

In a sense, it was. More than a hundred thousand had descended upon Porto Alegre, Brazil, to attend the World Social Forum, a conference intended to offer a progressive alternative to the much smaller, and much more famous, World Economic Forum meeting at Davos, Switzerland *(see "Letter from Davos," April 2005)*.

Just past the showers was a sprawling collection of wooden huts, connected by a canvas spread across their roofs. This was the free-software lab. To the right, there was a training room, with more than 50 PCs arranged along long tables. At the far end was a large screen, where 20 to 30 kids were watching an instructor explain the workings of some video-editing software. Every machine was running free software only—GNU/Linux as the operating system, Mozilla as the browser, and a suite of media production software, most of which I had never seen on any machine anywhere.

The room was being prepared for what seemed like a disco. Three DJ-like characters were huddled over a table full of machines, testing sound and twiddling fantastically elaborate controls. They were not DJs, however, but VJs: video jockeys who were preparing a demonstration of the tools they had built (as they described it) for "recycling culture." The music would, for all I know, not have been out of place in the coolest New York dance club; but the images were a collage of television and color presented in a way that I had never seen before, anywhere. As the music played, video samples were scratched across the screen. The VJ operated a turntable-like controller, which drove powerful digital video equipment designed to mix images, not records.

In another room, the yellow light filtering through the canvas roof bathed another 50 machines. John Perry Barlow, former lyricist for the Grateful Dead and cofounder of the Electronic Frontier Foundation, sat stooped over his PowerBook chatting with someone. He looked up with a smile. "It's [New York *Times* writer John] Markoff at Davos." Obviously, Wi-Fi bathed the room as well.



Campsite, World Social Forum, Porto Alegre, Brazil, 2005

Inside the room, a group of five or six Brazilians was waiting there to meet us. A film crew waited as well. They were shooting a documentary. The Brazilians were our guides, and I was there to understand what a "free software lab" was all about.

Stallman's Good GNUs

Everyone who reads *Technology Review* must have heard of "free software." It was on MIT's campus twenty years ago that the Free Software Foundation was born; it was an MIT researcher, Richard Stallman, who presided at its birth. Free software is code that carries a promise. Actually, it carries *five* promises (four explicitly, and one by implication), according to the foundation's definition of free software. Geekily numbered starting with zero, the promises are

> *(0) The freedom to run the program for any purpose;*
> *(1) The freedom to study how the program works and adapt it to your needs;*
> *(2) The freedom to redistribute copies so you can help your neighbor;*
> *(3) The freedom to improve the program and release your improvement to the public, so that the whole community benefits.*

The first and third freedoms imply a final, and equally important, freedom: access to the source code of the program. Software that offers anyone these freedoms is free; software that compromises any of them is not.

Stallman launched his movement as a reaction to changes in the environment within which software was written. In the world he had known, programmers were a sort of ethical scientist. Coders worked on common problems; they shared the knowledge that their work produced. More than 60 years ago, sociologist Robert Merton said of science, "Incipient and actual attacks upon the integrity of science have led scientists to recognize their dependence on particular types of social structure"; so, too, did Stallman believe that the freedom of programming faced "incipient and actual attacks." Its defense, he believed, would depend upon "particular types of social structure." He thus set out to build one: a social structure that would help coders preserve the integrity that he thought their discipline should have. The foundation of this structure would be a "free" operating system, inspired by Unix, but not actually Unix (and thus cleverly named GNU—GNU's Not Unix).

At the time, Stallman's ambition seemed to many unachievable. No single person, and no collective of volunteers, had ever succeeded in finishing a software project on the scale of a complete operating system. There was no reason to believe Stallman and his followers would succeed. But they began with first steps—the tools and scaffolding with which everything else could be built. These included some of the most important bits of GNU, like its compiler, the GNU Compiler Collection (GCC), and some of the most beautiful, like the Emacs editor. And each bit was wrapped in Stallman's single most brilliant idea: a license that would assure that the code he was building would forever remain free.

AP PHOTO/NABOR GOULART

The GNU General Public License, or GPL, is a copyright license. In the language of the free-software movement, it is also a copyleft license. Like any copyright license, it imposes conditions upon some uses of the products it governs. Like any copyleft software license, it includes among those conditions the requirement that changes to the protected code must be shared if they are redistributed. The copyleft requirement is a benefit for some (those who share the goal of spreading free software); it is a curse for others (those who would like to add to the project and benefit exclusively from what they add). Stallman bet there would be enough who saw it as a benefit to build a free operating system.


Richard Stallman

Six years into the project, however, GNU still lacked a heart—that is, the "kernel" of an operating system that provides control of a computer's hardware. That part would not come from Stallman. In 1991, Linus Torvalds, a Finnish undergraduate, announced the beginnings of a kernel governed by the GPL. Hackers started integrating that kernel—which they dubbed "Linux"—into GNU. By the middle 1990s, there was a full, functioning, free operating system spreading across the Internet. By the end of the 1990s, GNU/Linux had become a powerful and free competitor to Microsoft's Windows operating system *(see "How Linu x Could Overthrow Microsoft," p. 64).*

Proprietary Systems

There are a million details to fill in before the story of free software makes sense to anyone who doesn't already know it. Can free software be used commercially? Yes, freedom promise 0 requires it. Can free software be sold? Yes, for whatever price the market will bear. Can businesses make money producing or supporting free software? Some think so, as the billions invested by IBM and Hewlett-Packard suggest. Does free software destroy the financial incentive to produce new software? Not necessarily. Free software simply makes improvements transparent, as they are in any number of other healthy, competitive markets.

But let's put those questions aside and focus instead upon a historical pattern: a practice is at one time "free"; something changes; that freedom is lost; in response, activists work to restore that freedom. Thus, coding had been free; changes in the market had rendered it unfree; free-software activists acted to restore that freedom.

As I listened to the Brazilians explain the free-software lab, I began to realize that this pattern was recurring. They were doing for culture what Stallman had done for software. The lab was not so much about "free software." It did not, for example, teach people how to make free software. Its aim instead was to help them build free culture using free software. The lab offered "workshops about video editing, audio editing, collaboration tools, [and] online collaboration," all "on top of free software." But the objective of this teaching wasn't, or wasn't just, better software. The objective was a different economy for culture. Culture itself, as one Brazilian explained to me, should be free, meaning, he said, "free as in free software."

The parallel between free software and free culture is strong, though bringing it out will require some distinctions. For unlike software, culture has always had an element of proprietary control. And for most of our history, proprietary culture has actually encouraged free culture. But changes in the way culture is owned now make necessary the free-culture movement that Brazil is promoting. To understand that movement, we must understand what provoked it.

Proprietary culture is rendered proprietary by a system of regulation we call "copyright." In the U.S., copyright regulation was slight at first. In effect, the law reached only to the printing press, and by design, it regulated only a small proportion of creative work—just "maps, charts, and books." Very soon, however, the scope of the law began to grow. By 1831, it covered music. In 1870, it expanded to cover paintings, statues, and, most importantly, "derivative" works, meaning work based upon an earlier work—a translation, for example, or a play based upon a story.

These expansions were reasonable enough, each the product of a self-conscious legislative change. But early in the 20th century, the law became latched to a device that would produce unimagined changes in copyright's reach. For in 1909, through a mistake in codification (literally: it was an error in the wording used in the statute), the exclusive right that copyright protected was defined to be not only the right to "publish" or "republish" but the right to "copy." That change didn't matter much in 1909: the machines for making copies were still printing presses, and no one believed a schoolchild writing out a poem 50 times so as to memorize it was committing a federal offense. But as the machines that copied became more and more common, the reach of copyright law became more and more extensive. At first it was commercial machines that bore the burden of the law: player pianos, radio, cable TV. But in the 1970s, and for the first time, a printing press to which the common folk had access—the "copier"—became the target of extensive litigation.

These expansions in the law were balanced by important, built-in limitations on copyright. "Fair use" is one important limitation. But the most important was the product of a formality. To get the benefit of copyright protection, an author had to "opt in" to the copyright system: a work had to be registered; after an initial term, the registration had to be renewed; and the work had to be marked (©). No more than 50 percent of work published in the 19th century was registered. More than 80 percent of that registered work was never renewed. Copyright law thus automatically narrowed its reach to work presumptively needing the protection of copyright. It left much published work (and the overwhelming majority after an initial term) free.

This opt-in system was changed, however, in a series of amendments to American copyright law beginning in 1976. After these changes, creative work was *automatically* protected by a federal copyright, whether or not the work was registered, without any need to renew the copyright, and whether or not the work was marked with a funny little ©.

AP PHOTO/DOUGLAS ENGLE

Copyright law had always been conditional. It was now unconditional. It had always automatically narrowed its reach to work presumptively needing the benefit of copyright protection. It now reached all work, regardless of whether it needed any copyright protection. There was no evil conspiracy behind this change. Its purpose was perfectly benign: to simplify copyright law. The formalities of the old system were a bother. Abolishing them would remove that bother. But the consequences of abolishing these formalities were dramatic: we moved from regulating a minority of creative work to regulating all of it. Call this copyright's "first big change."

The second change is even more dramatic. To see the point, notice first how little the law of copyright regulates ordinary uses of creative work. Reading a book, for example, is not a regulated (by copyright law) use of the book. It's a free use: reading a book creates no copy. To lend someone a book is not a regulated use: it creates no copy. And to sell someone a book is not a regulated use: it creates no copy. These ordinary uses are beyond the reach of copyright law. Or put differently, copyright law leaves these ordinary uses immune from regulation.



Journalists using Linux, World Social Forum, 2005

But in the digital world, this immunity disappears. It is the nature of digital technologies that every use produces a copy. Thus, it is the nature of a copyright regime like the United States', designed to regulate *copies*, that every use in the digital world produces a copyright question: Has this use been licensed? Is it permitted? And if not permitted, is it "fair"? Thus, reading a book in analog space may be an unregulated act. But reading an e-book is a licensed act, because reading an e-book produces a copy. Lending a book in analog space is an unregulated act. But lending an e-book is presumptively regulated. Selling a book in analog space is an unregulated act. Selling an e-book is not. In all these cases, and many more, ordinary uses that were once beyond the reach of the law now plainly fall within the scope of copyright regulation. The default in the analog world was freedom; the default in the digital world is regulation. Call this copyright's "second big change."

When you tie these two big changes of copyright together, you get a "truly profound change." Not only is the reach of the law dramatically larger because copyright now regulates all rather than a minority of work, but the effective scope of the law is dramatically larger because copyright regulates all uses rather than just some. The U.S. Congress self-consciously made one of these two big changes, but it didn't know how far-reaching its legislation would be, since it couldn't foresee the eventual universality of machines that copy.

Control Issues

But if in fact the scope and reach of copyright law have expanded so radically, why hasn't anyone noticed? Why aren't copyright holders celebrating?

Simple answer: the expansion of copyright regulation has been offset by an equally radical diminution of its effectiveness. Though in theory an opt-out copyright regime *plus* digital technology means that everything is presumptively regulated, in practice, digital technologies have meant that this regulation is irrelevant. Digital technologies were designed to enable perfect copies; they were not designed to enable control over these copies. The perfection and freedom of digital technology, including the Internet, have thus led to a Roman feast of copyright infringement. Digital tools make it simple to share data with your 10,000 best friends, so people share data with their 10,000 best friends. The United States may be a nation of drivers who stop at red lights—even deserted red lights, in the middle of the night—but its citizens didn't even hiccup when slurping down peer-shared creative content, copyright notwithstanding. Whatever the law says, actions speak louder than words. And it is the actions of ordinary users that worries industries that depend on copyright, such as publishing, music, film, and software.

That worry has now prompted a response, and it is this response that in turn worries the free-culture movement. Digital technologies are only technologies: they are made by humans, and they can be remade by humans. If existing digital technologies have so far denied copyright holders control over how the fruits of their creativity get used, then future digital technologies can be remade to restore control to those same copyright holders. In fact, that's just what is happening.

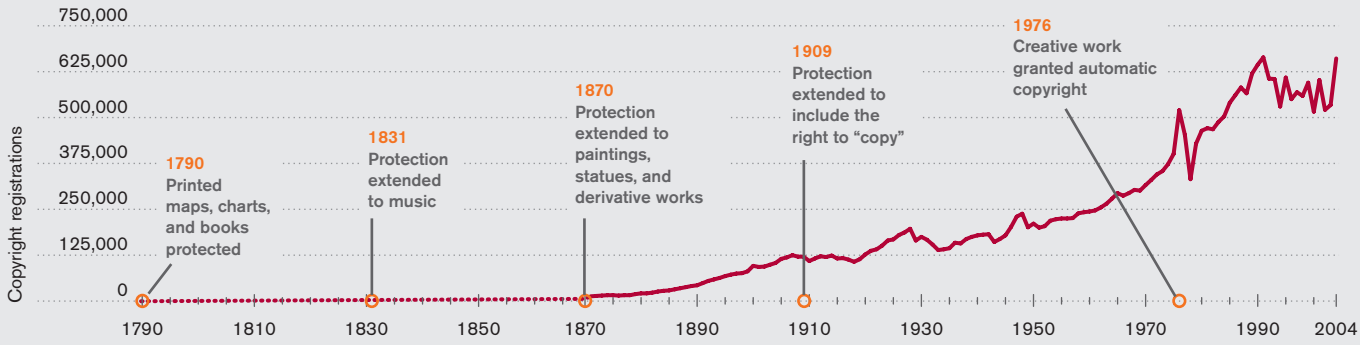
This restoration of control operates under the name "digital rights management" (DRM). DRM, and the myriad of supporting changes in technology that it will demand (for example, the addition of dedicated "trusted computing" chips to new computers), will build *back* into the architecture of the digital world the control that the original architecture of the digital world disabled. Nor will it stop there: copyright owners want more. Current DRM proposals reach far beyond the balance of proprietary and free culture in the analog world. If enacted, they would enable a copyright holder (or software creator) to, for example, dictate how many times you can read the e-book you've "bought," or how many times you can move it from one machine to another. Whatever uses you can imagine for a digital device, imagine DRM controlling them. That's the potential of this technology—a potential that reaches far beyond the limits of predigital copyright regulation.

Now, economists and others of a capitalist bent *(see "The Creators Own Ideas," p. 56)* will argue that it's not at all obvious that expanded regulation would be bad. They'll tell you that in many cases, giving property holders the power to control (or "discriminate") in uses of their property actually increases the total wealth of society. So we shouldn't necessarily condemn the tightening of control that DRM will produce in cyberspace, at least if it increases social wealth.

I don't want to quibble with economists (although I *do* answer Richard Epstein's objections to this essay: see "Rebuttal" on page 63). My point is less ambitious: it is simply to remark that the prospect of such tight controls would have seemed bizarre even three decades ago, and that we need to think quickly to decide whether we want such controls in the space of culture. When the Internet gives copyright owners perfect control of their content, then, since it's all automatically copyrighted, every use of it will presumptively require permission. We will then no longer live in

AP WIDE WORLD/SILVIA IZQUIERDO

The Evolution of Copyright Law



AN ESTIMATED 150,000 WORKS WERE REGISTERED BETWEEN 1790 AND 1870. SOURCE: U.S. COPYRIGHT OFFICE

a free culture, but in a "by-permission" culture. And these permissions will no longer be policed by courts or the law but rather by software code.

This is the control that the free-culture movement fears. Theoretically, digital technologies give the law the right to regulate culture to an unprecedented extent. DRM will turn that theory into practice. Do we know enough to conclude that the benefits of that practice will outweigh the costs? Do we even know enough to understand the costs?

DRMatically Bad

The case against DRM comes in two flavors, the familiar and the more obscure.

The familiar complaint is about the exclusivity of markets: maybe the price of reading an e-book will be too high; maybe too many people will be shut out of the market. That's a real concern in developing nations around the world, where the cost of both proprietary code and proprietary culture is wildly beyond the means of most people. Still, it's a concern that market apologists can quickly dismiss (see Epstein).

But consider the second complaint against DRM—one generally missed by the market apologists. This complaint is more fundamental: DRM abridges our personal freedoms and inhibits cultural transmission. To appreciate it, step back from the digital for a moment. Think instead about human culture as a whole. Participation in cultural life involves a practice that we could call "remix." You read a book. You tell the story to friends. You see a movie that inspires you. You share its story with your family, to spread that inspiration.

Remixing uses the fruits of someone else's creativity. There's no guarantee that it does any favors to the work that is remixed. There's no requirement that it treat the work respectfully or kindly. The freedom to remix is a freedom to ridicule or respect. Fairness is not the measure. Freedom is.

It is almost impossible to imagine a culture thriving if its people are not free to engage in this kind of practice. Remixing is how culture gets made. The acts of reading, or criticizing, or praising, or condemning bits of culture are how we create things. This is true whether the culture is commercial or not: you cannot limit remixing to things in the public domain. In our tradition, we have been free to remix, whether the stuff remixed is copyrighted or not.

This freedom, however, has been limited, historically, by an important technological fact. Since the dawn of humankind we have been free to remix, but the technology of remixing has been words. We use words to remake our culture. We use words to criticize or incorporate. The ordinary ways in which culture gets made are textual. No one restricted the freedom to remake culture because, in free societies at least, no one purported to restrict what ordinary people did with ordinary words.

So what happens when the ordinary ways in which culture gets remixed change? What happens when the ordinary tools of remixing change? Do the freedoms to remix change as well? Will we be more or less free to remix culture in the 21st century than we were in previous centuries?

When the Internet gives copyright owners perfect control of their content, then, since it's all automatically copyrighted, every use of it will presumptively require permission.

Consider how the kids in Porto Alegre think about remixing. They remix culture with words, certainly. But they want to build the capacity to remix more than words. They hope to use computers to remix culture. For most of us, computers are a way to type fast. But for most of them, computers will be a way to speak, using sounds and images, synchronized or remixed, to make art or remake politics.

It is extremely hard to describe the new kinds of remixes that digital technologies enable. That may be their point. You could look at some examples at atmo.se. But if you're stuck with your imagination, then you need to extrapolate from examples you've seen so far. Think about the very best examples of digital media that you've experienced (perhaps the JibJab remix of "This Land Is Your Land"), and then remember they're not likely the product of Sony or Disney. Digital technologies have inspired an extraordinary range of creativity,

in part because they lower the media market's barriers to entry, which in turn invites a much wider range of participation.

We're just now beginning to see the consequences of this democratization of artistic means. A couple years ago, for example, a young filmmaker named Jonathan Caouette began playing with his boyfriend's iMac. The iMac came bundled with Apple's iMovie program. Caouette was smitten with it. And while he had never studied film, he had shot an extraordinary amount of video growing up. He began obsessively to digitize this video. Then, using iMovie, he remixed it. The result was a film that was the hit of Sundance and Cannes in 2004: *Tarnation*. It cost Caouette just $218 to make this film.

The point is not that anyone can make a Cannes hit. But it is enough to recognize that many more people (indeed, millions more) could make good films. New digital technologies could enable an explosion of creative work.

Now there's no problem, of course, with this sort of creativity if the underlying remixed culture is "free": Jonathan Caouette didn't have much trouble making his film since he remixed his own footage. But what if you wanted to use these technologies to remix copyrighted content with your own content?

The short answer is, you couldn't. Under today's rules, remixing copyrighted digital content is infringing the rights of the copyright holder.

That in turn makes concrete the second, less familiar, complaint against DRM: if the technology permits the most extreme interpretation of existing copyright law, remixing will not become merely difficult. It will be effectively impossible—without clearing the rights first. If content is locked in code that requires permission before it can be reused, or remixed, then that permission will poison the practice of remixing. A kind of creativity—familiar since the beginning of culture—will thus be lost to digital culture and, as digital culture occupies more and more of our activities, to culture as a whole.

This, finally, is the link between the free-software and free-culture movements. In both, there was a practice that was essentially free. In both, a change in the environment of the practice removed that freedom. With free software, the change was the rise of proprietary code. With free culture, the change was the radical expansion of the reach of copyright regulation. Technology made both of these changes possible. Both the free-software and free-culture movements in turn use technology and law (through copyright licenses) to restore the freedoms that proprietary code and culture removed. Each proceeds through the voluntary efforts of creators to preserve a wider range of freedoms for their successors. Each seeks a world without the controls that the extremes of proprietary assertion produce.



Gilberto Gil and John Perry Barlow

Truly Free Markets

When most people trip upon these free movements, their initial reaction is that both are implausibly utopian. They read "free" to be a rejection of basic economic principles.

But the economy of free software is still an *economy*. It produces wealth; it inspires growth; it spreads services broadly within a society. It functions differently than the economy of proprietary software—different scarcities are traded—but it is still an economy. And literally billions of dollars have been invested to make it flourish.

The same is true of free culture. Many read "free culture" to mean that artists don't get paid. But here, too, the difference is not that one approach (proprietary culture) builds an economy while the other (free culture) does not. In the way that I've use the term, free culture describes the economy that governed creative industries for at least the first 186 years of the American republic. More importantly, proprietary culture has never yet governed any creative economy, anywhere. No society has ever imposed the level of control that the proprietary culture of digital technologies and DRM would enable.

The kids in Porto Alegre were resisting economic shifts away from the old balance that has defined the Western tradition. The economy that they would build doesn't deny the importance of copyright (indeed, the licenses necessary to build free software and free culture depend upon copyright). But it revises copyright to fit a digital age more effectively. It structures the law in light of technology, to produce the greatest opportunity for creativity and growth that the technology might offer.

These are improvements in efficiency. They aim at increased wealth. But there is a growing politics supporting both movements that has little to do with efficiency or wealth. This is payback politics, tied less to ideas than to an increasing global frustration with the United States.

The cause is not hard to see: according to the United States, Brazil, for example, is a pirate nation. The International Intellectual Property Alliance (which, its name notwithstanding, represents U.S. copyright interests) estimates that this piracy cost United States copyright industries close to $1 billion last year. Consequently, the U.S. has begun to put pressure on Brazil. That pressure has produced an unsurprising reaction against the stuff that makes it possible for Brazil to be a pirate nation—proprietary code and proprietary culture.

For there's another way to reckon the cost of the proprietary. According to the Brazilian government, for example, Brazil sends close to $1 billion to the north each year just to pay for software licenses. So as the Brazilians see it, tongue firmly in cheek, this proprietary stuff is a bad thing all around—costing the U.S. $1 billion, and Brazil $1 billion as well.

The obvious solution is to dump the proprietary stuff. So the Brazilian government is pushing itself and the nation to substitute free software for proprietary software. As one member of the government said during a speech at the World Social Forum, "We're against software piracy. We believe Microsoft's rights should be respected. And the simplest way to respect their rights is for Brazilians everywhere to switch to free software."

The Brazilian government is beginning to internalize the tenets of the free-culture movement as well. Brazil's minister of culture, Gilberto Gil, is leading a push for practical reform of the

AP PHOTO/NABOR GOULART

copyright system. His ministry has launched a project called Points of Culture (Pontos de Cultura) that will establish free-software studios, built with free software, in a thousand towns and villages throughout Brazil, enabling people to create culture using tools that support free cultural transmission. If things go as planned, the result will be an archive of Brazilian music, which will be stored in digital form and governed by a license inspired by free software's GPL. The Canto Livre project will "free music" made in Brazil, for Brazilians (and the world) to remix and re-create. And like a free-software project, it achieves that freedom on the back of copyright.

Gil is emphatically not against copyright. He's one of Brazil's most successful musical artists, which means he has benefited greatly from copyright. But he is also one of the very few Brazilian artists to make it outside of Brazil. And he is convinced that a different kind of economy might spread Brazilian creativity more broadly.

So the U.S. calls them pirates, and they reform their ways—not by more faithfully buying our products, but by finding ways to remain creative without infringing our rights. This is free software "ported"—as software engineers say—to free culture, and it inspires all the hype typical of such movements. "We're hoping," the leader of the free-software lab explained, "everybody is going to start producing their own media content and then they won't have to watch TV anymore."

That's a rather grand ambition, no doubt. But before you dismiss it as mere youthful idealism, consider this: had you met Richard Stallman in 1984, would you have believed him? And remember, he didn't have the government of the fifth-largest nation in the world behind him.

If technology permits the most extreme interpretation of existing copyright law, remixing will not become merely difficult. It will be effectively impossible.

Imagine All the People

Two nights before my trip to the free-software lab, I attended a free-software rally at the same youth camp. Really. A rally. I arrived with Minister Gil and John Perry Barlow. The place was packed. There were hundreds inside the tiny tent; there were many hundreds more huddled outside. We were seated near the front, the only three with chairs. The evening began with some lectures, then followed with some music.

You can't imagine this scene. Or at least you can't imagine this scene as a rally for free software. I've seen free-software rallies in the U.S. They're populated by geeks with ponytails. This was something very different. The tent was divided evenly between men and women. Geeks were in the minority. Most of the people at the rally were astonishingly beautiful, and amazingly articulate. They were young and intensely passionate. And they were chanting free-software slogans. It was Woodstock without the mud and squalor, and with a penguin in the middle of the room.

For a bit, I was terrified a riot would break out. There was no room to move. We were physically squeezed on all sides. I tried to imagine Donald Rumsfeld in the same situation. One or two police stood at the back, just in case. But the crowd was peaceful, just jubilant.

Just as Gil started to speak, however, a handful of masked protesters appeared out of nowhere and positioned themselves right up front, brandishing posters. They were attacking the government. They were attacking Gil. They were supporters of pirate radio. They wanted a third layer of freedom—free radio spectrum, in addition to free software and free culture—and the government had resisted them. It was hypocrisy, they screamed. I was sure it would turn ugly—until Gil did something unimaginable in U.S. political culture. He stopped, and he engaged them. He argued with them. He listened to their arguments. A deputy joined Gil in the argument. They paused to listen to the protesters argue back. They then responded again, and Gil slowly whittled the opposition down. Midway through all this, a kid wearing a white T-shirt stood up just in front of us. Emblazoned on the back was the slogan "This is what democracy looks like." Eventually the crowd rose in Gil's support. They wanted more music. The protestors yielded. Gil was asked to sing some songs.

By the end of his performance, the crowd was in a euphoria. Imagine a mix between RFK and John Lennon, and you have a sense of this man's power and charisma. As we left, the crowd left with us—mobbing Gil. Teenage girls wanted him to sign their backs. Men and women gave him anything they had to sign. He was grabbed again and again. If people disagreed with him, he would stop and engage them. He argued, but always with respect.

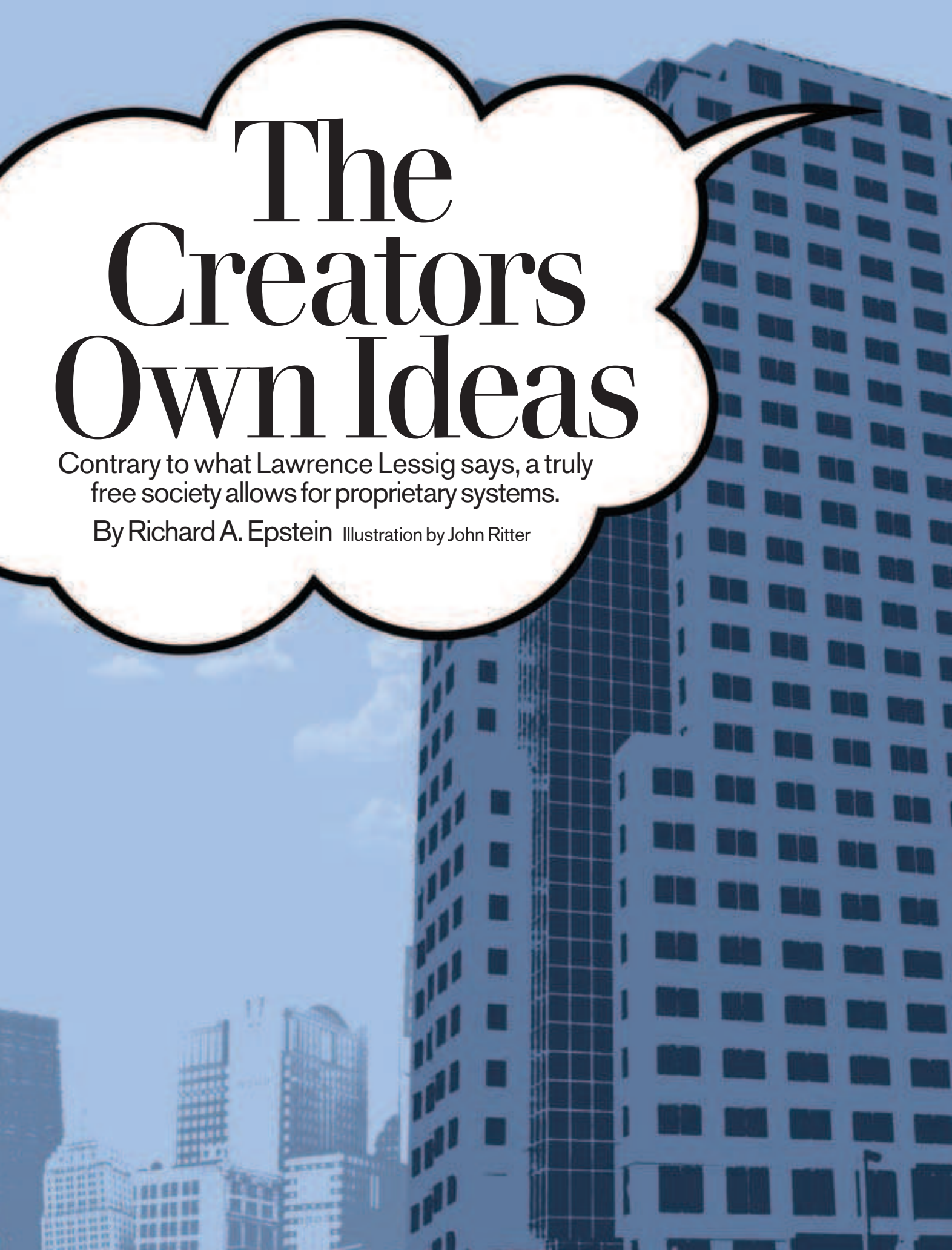
We were finally pushed onto a golf cart and then into a government car, so he could escape. But even here, when someone knocked on Gil's window, he rolled it down and continued arguing. He yelled out his final words as his driver (a man with less patience than Gil) sped away. When the window was closed, and after a moment of silence, I tried to explain to Gil just how extraordinary that scene appeared to American eyes. I said that I could never imagine the equivalent in the United States, with anyone actually in power.

"Yes, I know," he said, smiling. America, he explained, has "important" people. "Here, we are just citizens."

These "citizens" are building something. We won't notice it until it is big enough to see from America. But if it gets that big, nothing will stop it. Just as the free-software movement has built an economy of free software, the Brazilians—and others around the world—will have built an economy of free culture, competing with, perhaps displacing, but no doubt changing the proprietary culture that finds itself dominant now. ■

Lawrence Lessig is a professor of law at Stanford Law School. He is the author of The Future of Ideas *and* Code and Other Laws of Cyberspace. *His most recent book,* Free Culture, *was released in paperback this spring and is available as a free download at www.free-culture.org.*





The Creators Own Ideas

Contrary to what Lawrence Lessig says, a truly free society allows for proprietary systems.

By Richard A. Epstein Illustration by John Ritter

My task here is to write a response to Larry Lessig's meditation on the free-software movement and its relationship to the general law of copyright *(see "The People Own Ideas!" p. 46.)* But as the dry tone of my first sentence suggests, we have very different approaches to our common topic. Lessig is a master at weaving personal vignettes with structural arguments. The vignettes are intended to introduce an intimate personal dimension to the arcane world of intellectual property. His readers receive a gut-level education about the immense impact that legal rules have on ordinary people, whose voices, he tells us, can only be heard above the din if they speak in unison.

I demur. The selective imagery of eager students in Porto Alegre, Brazil, "remixing culture" using free software does nothing to address the central policy issues around intellectual property. The complex trade-offs needed to govern software and copyright aren't illuminated by the artful juxtaposition of real users of free software with the nameless stick figures stuck with proprietary alternatives. One could as easily paint a picture of high-spirited inner-city youths mastering Microsoft Office under the benevolent gaze of the Bill and Melinda Gates Foundation. Neither helps.

Private and Common Property

My qualified defense of proprietary software rests on my general approach to property rights. It may seem odd that I see land law as a place to begin thinking about copyright law in the digital age, but in the law, continuity counts for more than novelty. While we always have to tend to the differences among different forms of property, we are likely to make fewer mistakes by proceeding carefully from established understandings.

Every legal system in history has blended two separate property regimes: the private and common. Both are important to software and copyright. Private property confers on individual owners exclusive rights to the possession, use, and disposition (sale, lease, mortgage, gift) of some given tangible resource. Virtually all civilizations start with a decentralized system in which the person who first takes an unowned thing is entitled to keep it against the rest of the world. Providing a plot of land or individual object with a single, determinate owner facilitates its effective use. The farmer who sows today knows that she can reap tomorrow, without fearing the incursions of others. The ability to sell, lease, or mortgage property allows for everything from a simple transfer of land from person A to person B to the formation of complex coöperative ventures among multiple parties. The GNU General Public License (GPL) that Lessig so admires offers a shining example of how this last, iterative process works.

Any system of private ownership requires state enforcement, first, to protect private property from forced occupation, misappropriation, and invasion, and second, to enforce voluntary deals. But any theory of property rights that includes a key role for the state should also emphatically reject the use of centralized state power to determine who shall own what resource or why. Governments, for instance, should not pick technologies.

In all legal systems, however, a system of private property rests on an infrastructure of common property. The air we breathe, the roads we travel, and the language we speak cannot easily be reduced to private possession. They remain part of the commons because their separation impedes respiration, transportation, and communication. At the edges, we recognize useful exceptions. Although everyone may use the word "monopoly" to describe a market with a single seller, only Hasbro may market a board game with hotels and a jovial top-hatted mascot under that trade name. The private creation of a trade name pulls that name out of the linguistic commons for the limited purpose of identification.

Owners and Nonowners

These simple observations can be generalized. Property rights are organized to minimize the obstacles to human prosperity and well-being by maximizing the public benefit that emerges from the self-interested actions of many individuals. Common property works when we want, say, to travel freely on a river. Private property works when the development and trade of separable assets creates enormous gains. But the justification for private rights in everything from sponge cake to software has to be social. Private property provides the right incentives for innovation, from which *nonowners* benefit through voluntary exchange.

In general, private property is a great bargain for society. Let's assume that Bill Gates's net worth is $45 billion. That's a lot, but it's no big deal compared to the gains his customers have received from purchasing Microsoft products. My copy of Microsoft Office may have cost me $500, but that is a tiny fraction of my gains in productivity. The most important gains from all forms of property, whether tangible or intellectual, accrue to the nonowner who buys the products of the owner. The price one actually pays for a thing is almost always less than the amount one *would* pay if necessary. The difference, called consumer surplus, is a pure gain for the buyer, and it exists because private ownership gave the seller the incentive to create or maintain the thing. In other words, granting a temporary patent or copyright monopoly to get the benefit of a new product now—rather than having to wait for some free product later on—is usually a good deal for both the producer and the consumer. This system of property rights isn't antithetical to free software or "free culture." Indeed, it is their very foundation. Let's start with software.

Freeware versus Payware

Lessig's defense of free software reads more like a disquisition on good and evil than a measured assessment of its benefits compared to proprietary alternatives. But the "four freedoms" con-

tained in the GNU GPL, which governs the way much free and open-source software is distributed, weren't inscribed on tablets brought down from Mount Sinai. They were created in the 1980s by Richard Stallman, an MIT computer scientist with a particular social agenda. Lessig describes these four freedoms and their functions cogently enough in his essay. The bottom line: free software means free and open access to a program's source code.

It sounds innocent enough. But as with every contract or license, there's a catch. No legal system ever creates unlimited rights, and every freedom has its correlative duties. In the case of the GPL, the kicker is that anyone who incorporates open-source software into his work must release any derivative work under the same license. The precise language is as follows: "You must cause any work that you distribute or publish, that in whole or in part contains or is derived from the Program or any part thereof, to be licensed as a whole at no charge to all third parties under the terms of this License." The word "must" says it all. Content protected by a general public license is just that, licensed. Software distributed under the GPL should not be confused with ideas, writings, and inventions lodged happily in the public domain, available for all to use as they see fit, without any restrictions.

The GPL, in short, is vintage capitalism. Stallman created his own software from scratch, and the ordinary rules of property and contract let him license that software on whatever terms he chooses, with no questions asked. Those who don't want to play by the rules of the free-software community are free to do business with Microsoft. Likewise, Microsoft is free to say, "Forget that free-access stuff: you can license our software, but you cannot see all our source code. If you don't like our conditions, then you may switch to some open-source product." Take-it-or-leave-it works both ways.

Why, then, prefer software bound to Stallman's particular mix of freedoms and restraints to software that is proprietary or in the public domain? The defenders of free software often claim that their GPL inspires production and creativity, while proprietary software encourages secrecy. But this is a false opposition. The law of trade secrets can also inspire creativity; it recognizes the premise that some people will invest in a new invention only if they can retain the exclusive right to control its use. They can keep the code dark and sell the products made with it; or they can license the use of the code under a confidentiality agreement. Protecting trade secrets ensures that original creators are rewarded for their work. By contrast, open-source projects reward those who contribute to the code later.

So which plan is better? Perhaps the choice is not so stark. IBM makes millions on its database and server software yet actively encourages its customers to use the open-source Linux operating system. Sun Microsystems is relicensing its Solaris operating system under open-source terms in order to let its own software developers tap into the thriving open-source community. Even Microsoft shares its code, on a limited basis, with outside developers of Windows programs. If the copyleft movement (as it sometimes likes to call itself) requires that all derivative work be governed by the GPL, that's fair enough; developers know the terms of the deal. Yet proprietary firms can profit from similar networks of license agreements, albeit agreements that take a different form. The state's job is to enforce both sets of arrangements as written (with the caveat that private contracts are invalid if they create monopolies in restraint of trade).

We can now see why Lessig's homage to free software is at odds with the principles of a free society where people can choose whatever business arrangements they prefer. We shouldn't praise the Brazilian government for "pushing itself and the nation to substitute free software for proprietary software." We would be equally wrong to urge the Brazilian government to promote proprietary software. In free-market societies, it is wholly illiberal for governments to take *any* side in controversies involving varying business models. A government's role as a neutral arbiter is compromised whenever it engages in propaganda to persuade folks to prefer one type of contract to another. By putting its thumb on the scale, it makes true competition impossible. Arbiters cannot be cheerleaders.

The same principle, I believe, applies to the state's own procurement decisions. Governments have fiduciary duties to their citizens similar to those that boards of directors owe to shareholders. Their job is not to satisfy their own ideological predilections; they should buy the software that offers the best combination of price and quality. The great threat to free culture is not proprietary software. It is the dogmatic insistence that one form of industrial organization is *a priori* better than its rivals.

Lessig's homage to free software is at odds with the principles of a free society. It is wholly illiberal for governments to take any side in controversies involving varying business models.

Social Reasoning

That same overconfidence about software licensing pervades Lessig's treatment of copyright. No matter one's political beliefs, it is critical to remember the strong economic imperatives that drive modern societies to legislate some form of copyright protection. Just as we protect private rights in land for the benefit of the community, not solely for a property's owner, so too we have a social reason to protect writings and other intellectual creations.

As John Locke would have it, a just society recognizes the natural rights of its citizens, including the right to protection of their productive labor. But copyright has an additional justification: it fosters huge positive contributions to culture, in the form of novels, movies, manuals, music, and other works. Some creators are motivated solely by the desire to create and would be happy to distribute their works under simple terms such as a Creative Commons license requiring attribution only. But for most authors, compensation matters, and we increase their production by limiting the rights of others to copy their work. Of course, authors who claim copyright protection today necessarily build on the efforts of prior

writers. But Lessig's rhapsodic praise of free culture ignores the necessary trade-offs between producers and users that any mature system of copyright must take into account.

Balancing Acts

In the end, all is a search for balance. Here are the key trade-offs:

Copyright duration. The ownership of land is normally indefinite. But the U.S. Constitution allows for Congress to issue copyrights for limited periods only. Why the difference? Because there is no sensible way to return privately owned land to the commons. Forcing the current owner out after 50 years would create a free-for-all, because only one owner can possess a plot of land. But writings (including software) are different, because many people can use them without depriving others of their use. The only question is how long to wait before returning them to the public domain. Lessig and I agree that the current rules are too generous. In the 19th century and for most of the 20th, U.S. copyrights initially expired after 28 years, a rational length of time. But the 1976 Copyright Act lengthened that period to 75 years, and the Sonny Bono Copyright Term Extension Act (CTEA) of 1998 gave producers another windfall, adding 20 more years—even for works whose 75-year copyrights were about to expire. Disney and the Gershwin estate didn't do anything to deserve such extensions on their expiring copyrights. (Remember, someone with one year left to run on a copyright gets a lot more out of a 20-year extension than a new author whose 20 extra years start in 2080.)

Scope of protection: derivative works and DRM. Opposition to the CTEA shouldn't translate, however, into reluctance to extend copyright protection to derivative works like the French translation of my latest novel. The extra income stream is an added incentive for the original author, while rivals must compete by producing novel works rather than derivative ones.

We should also welcome the expanded options that digital rights management (DRM) provides for marketing new works. Forcing people to pay for films and music on a per-use basis is a sensible response to the technologies that allow protected works to be copied infinitely at close to zero cost. With old-fashioned books, a work's value to a second reader is built into the cover price. But there's no way to price an initial sale to cover anywhere from one to a million performances of a song. Charging by use allows for price discrimination between heavy and light users, which neatly brings into the marketplace those low-intensity users who are unwilling to pay the flat fee for records or tapes. DRM is no more threatening to free culture than metered phone calls.

Nor will DRM impede the "remixing" of bits and pieces of shared experience into new creative works. I can be inspired by Hemingway or Bellow to write my own masterpiece, so long as it is not a derivative work. Indeed, often the copyright law does not give sufficient protection to original creators. The old rules work well; the only problem is that an artist or author who wants to assemble snippets from previous works into something new can find it prohibitively expensive to acquire the rights to those snippets. What's needed is some fine-tuning around the edges.

Fair use. Section 107 of Title 17 of the U.S. Code contains a turgid account of the factors that determine whether any particular use of a copyrighted work is protected as a fair use—the limited use of the work of someone else in your own work. Fair use lets a critic quote from an author she hopes to savage: her article will be suspect if it does not show the basis for her judgment. Asking the author for permission won't work because the author will deny access to his enemies and allow it to his friends. So weakening the property right makes sense as a way to bolster the market. Similar arguments can be made for allowing use of copyrighted works in other cases, such as news reporting, teaching, and research, as Section 107 now dutifully provides.

The harder problems are those like the great 1984 case of *Sony v. Universal Studios*, in which the U.S. Supreme Court held that fair use allowed people to use the Sony Betamax VCR to record television shows. The Court ruled that Sony did not illegally aid copyright infringement because its equipment had "substantial noninfringing uses"; in fact, the justices reasoned that VCRs *expanded* the numbers of TV viewers. But the choice involved hard trade-offs. To hold Sony liable might have retarded the use of valuable new technology, but letting it off ran the risk of undermining the TV and movie industry's ability to protect copyrights. The Supreme Court's decision was proved right when VCRs opened up a new income stream for copyright holders.

These same trade-offs are at issue in this year's cause célèbre, a Supreme Court case pitting MGM against the operators of Grokster, a peer-to-peer file-sharing program that some consumers use to download pirated copies of songs or movies. The friend-of-the-court brief Lessig submitted in support of Grokster shows the same habits of mind that dominate his piece for *Technology Review*. The late Fred Rogers of *Mr. Rogers' Neighborhood*, who testified in *Sony v. Universal*, wanted his works to be freely available for noncommercial use: Lessig applauds this virtuous impulse and worries that suits against Grokster will frustrate the wishes of people like Rogers. So he wants Grokster to be free of liability even if individual file sharers should be punished. Fair enough; but once again he pleads his case through anecdote rather than solid legal reasoning.

My fundamental objection to Lessig's essay is that he argues by appealing to attractive examples of free spirits and not from legal principle, as a good jurist should. My son Benjamin is a young, gifted filmmaker in New York who depends on copyright protection for his livelihood. I would never argue, however, that we should have strong copyright protection just to help Benjamin's career. But Lessig's arguments from anecdote do the equivalent for his own cause. In spite of his fervor, he has not explained why the standard view, which offers sensible if limited protection of intellectual-property rights, is wrong. We have yet to learn why free culture depends on free software. For me, at least, the opposite is closer to the truth: free society also rests on the strong protection of proprietary software. ■

Richard A. Epstein is the James Parker Hall Distinguished Service Professor of Law at the University of Chicago. He was the editor of the Journal of Legal Studies *from 1981 to 1991 and of the* Journal of Law and Economics *from 1991 to 2001. His books include* Skepticism and Freedom: A Modern Case for Classical Liberalism. *Epstein taught a seminar on the intellectual origins of private property taken by none other than Lawrence Lessig.*

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Epstein is smart, but still wrong

Years ago I swore off responding to Professor Epstein in print—not because he's not full of ideas and very often right (he is both of those things, and more), but because it's so hard to get him to listen. (He once published an article attacking an argument I had made but insistently misinterpreted my position; no matter what I did, I couldn't get him to see that

we were actually in agreement.) But his response to my essay here proves that my resolve was misplaced. It is a brilliant and compelling argument for a very sensible position about copyright, software, and even culture. Save for quibbles on the margin, there's little with which I would strongly disagree.

Epstein contends that "every legal system in history has blended two separate property regimes: the private and common"; that "the justification for private rights...has to be social"; that we need a "social reason to protect writings and other intellectual creations."

All true. And nothing I've ever written says anything to the contrary. We need a balance (or "blend," as Epstein puts it) between the private and common. We need social justifications before we regulate anything, especially speech (as copyright inherently does). So the argument I've made in many contexts (both "from legal principle, as a good jurist should" and from real stories about real people, as good writers sometimes do) is just that we need to be skeptical about the explosion in regulation that goes under the name "copyright." I emphasize: skeptical, not condemning. Where regulation serves a progressive end, we should embrace it. Where it is little more than corruption introduced by special interests, we should condemn it.

Thus, Epstein is right that I do not explain "why the standard view, which offers sensible if limited protection of intellectual-property rights, is wrong." That's because I don't think the standard view *is* wrong. Nor do I condemn "proprietary culture." Proprietary culture has been with us from the start and for most of our history has served creativity and culture well.

What I do condemn is extremism—the shift from the standard view to an extreme version of "proprietary culture" that could easily become embedded in the digital economy.

I doubt Epstein endorses extremism, so it would be great to know how he justifies his Panglossian views. I described, for example, a very particular design of digital rights management (DRM) technology, one that prohibits a certain kind of cultural "remix." Epstein apparently has no problem with DRM. As he writes, "DRM is no more threatening to free culture than metered phone calls." But of course, the devil is not in the theory, but in the details. If DRM functioned *merely* as a metering mechanism, I'd agree. But Epstein is presuming that DRM's principal use will be for price discrimination. Whether DRM will be used for something more insidious is the question I was raising.

The DRM scheme that I was discussing would indeed "impede the 'remixing' of bits and pieces of shared experience into new creative works," as Epstein puts it. I am suspicious of this particular scheme—if only because I can't see any reason why the law should restrict my freedom to refer to culture just because I am using new digital technology. After all, the law left me free when I was using older technologies.

Epstein simply asserts that DRM won't have this restrictive effect. *Why*, he doesn't say. Instead he insists, "I can be inspired by Hemingway or Bellow to write my own masterpiece, so long as it is not a derivative work." But taking inspiration from Hemingway or Bellow is not "'remixing'...bits and pieces of shared experience." That was the subject of my question: What possible reason is there for the law to restrict remixing bits of shared experience? And what reason is there to believe that DRM technologies won't be so restrictive?

Finally, a word about Brazil's free-software pledge: I agree that there should be no *preference* for a particular model of software development, independent of the value that any particular model delivers. I oppose the slogan "Buy American"; I would also oppose "Buy Free." But if a government determines that the value to society from one model is greater than from another, then there's no principle of neutrality that says it can't push the more valuable model. ■

How Linux Could Overthrow Microsoft

The open-source movement is the largest threat the software giant has ever faced. Does Bill Gates have a plan?

By Charles Ferguson
Illustration by Steve Brodner

FOR AS LONG as most technologists can remember, there has been "Wintel," the $250 billion industry dominated by Microsoft's Windows operating systems and Intel's microprocessors. But "Lintel," or the Linux operating system and Intel, is now encroaching on this empire, and behind it is the entire open-source software movement, which threatens to overthrow the Windows industry. Faced with this challenge, Microsoft is showing classic symptoms of "incumbents' disease." Rather than remaking itself, Microsoft is using legal threats, short-term deals, and fear, uncertainty, and doubt to fortify its position. But this strategy probably won't work. The Linux operating system and the open-source model for software development are far from perfect, but they look increasingly likely to depose Microsoft.

With some improvements, the open-source model could even become the dominant global production model for software. If it does, it will be an irony. The open-source movement was launched 20 years ago by an antiestablishment technologist and for years was ridiculed by the mainstream computer industry. But it quietly drew more adherents every year, spreading first


OPEN
SOURCE

among iconoclastic hackers because its legal structure and culture offered them freedom from "the suits"—that is, the entire managerial, financial, and legal apparatus of the commercial technology sector. But now IBM, Hewlett-Packard, and Intel have become supporters of Linux and open-source development. Their goal is to reduce Microsoft's prices and power by commoditizing mass-market software.

If that happens, it will be a further irony. Microsoft achieved dominance by imitating the products of others, encouraging the copying of the IBM PC and cannibalizing the proprietary computer industry. But now a revitalized IBM, aided by Hewlett-Packard, Dell, Intel, and Oracle, is fomenting revolution, while Microsoft increasingly resembles the old IBM, an entrenched monopoly that survives by forcing the world to buy its high-priced, aging, increasingly bloated products. (Microsoft said in April that one server product will run Linux—a symbolically significant concession, but hardly a sign that the ship is turning.)

How open source will fare without an enemy like Microsoft is one of several open-ended questions it must face. But then, it's always faced open-ended questions, and those questions always, somehow, get answered. Indeed, at a recent conference, Linus Torvalds, the inventor of Linux, was asked about his long-term vision for it. He replied that he was an "anti-visionary." When people looked too far into the distance, Torvalds said, they missed things in front of them and stumbled. In fact, the next step for Linux is obvious: it is becoming big business, fast.

This because for all its flaws, the open-source model has powerful advantages. The deepest and also most interesting of these advantages is that, to put it grossly, open source takes the bullshit out of software. It severely limits the possibility of proprietary "lock-in"—where users become hostage to the software vendors whose products they buy—and therefore eliminates incentives for vendors to employ the many tricks they traditionally use on each other and on their customers. The transparency inherent in the open-source model also limits secrecy and makes it harder to avoid accountability for shoddy work. People write code differently when they know the world is looking at it. Similarly, software companies behave differently when they know that customers who don't like a product can fix it themselves or switch to another provider. On the available evidence, it appears that the secrecy and maneuvering associated with the traditional proprietary software business generate enormous costs, inefficiencies, and resentment. Presented with an alternative, many people will leap at it.

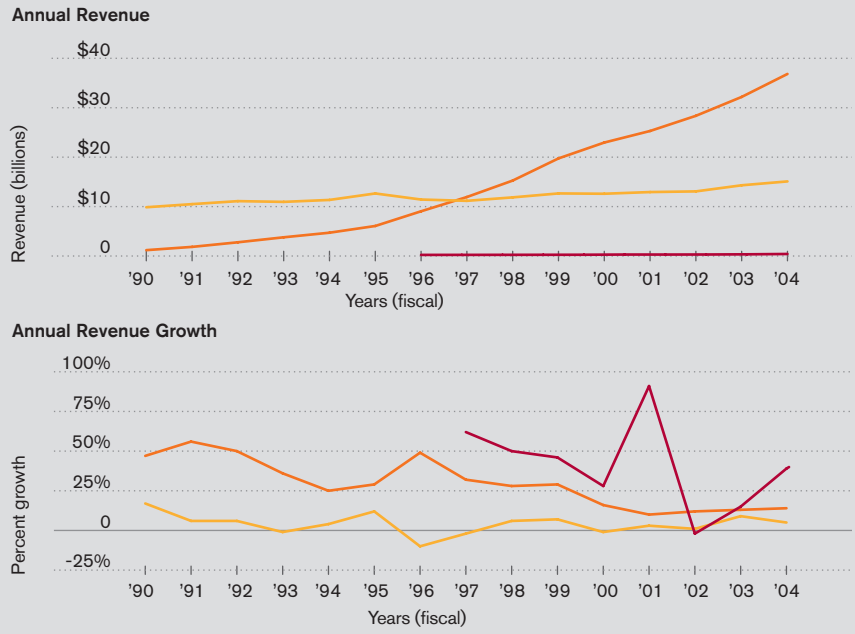
How Open Source Grew

The open-source model was invented by Richard Stallman, an exceedingly brilliant MIT computer scientist not known for his love of ideological compromise or corporate profits. In response to the fragmentation of the Unix operating system into proprietary, incompatible dialects, Stallman resigned from MIT in 1984 and started a crusade. He began work on an anti-Unix operating system called GNU, which stands (recursively, of course) for GNU's Not Unix. He created the Free Software Foundation to distribute that work and the idea of an open-source license to govern it *(see "Who Will Own Culture?" p 46)*.

Although Stallman is rather doctrinaire in his antipathy for business, the world is indebted to him. In 1991, when a 21-year-old Linus Torvalds wrote the original Linux "kernel"—the part of an operating system that controls a computer's hardware—for his personal computer, Stallman's ideas informed his decision about how to distribute it. Torvalds is a quietly confident, consummately practical man who has proved to be an impressive leader and manager as well as developer. His creation attracted interest from other programmers, who began to contribute improvements, with Torvalds informally coördinating their work. In the mid-1990s, Linux benefited from two potent forces. The first was the Internet, which enabled electronic software distribution and decentralized collaboration among many programmers working independently. The second force was growing frustration at the limitations imposed by proprietary software vendors—particularly Microsoft and Sun Microsystems.

And so Linux entered commercial use. Its first, and still most successful, niche was Web servers; for at least five years, the majority of the world's Web servers have used open-source soft-

Software Company Revenue Trends



	1996	2000	2004	Percent Change '96-'04
IBM Software	$11,426	$12,598	$15,094	+32%
Microsoft	$9,050	$22,296	$36,835	+307%
Red Hat	$9	$42	$126	+1,300%

SOURCE: IBM, MICROSOFT, RED HAT

ware. Then, several years ago, IBM started to contribute money and programmers to open-source efforts. IBM, Intel, and Dell invested in Red Hat Software, the leading commercial Linux vendor, and Oracle modified its database products to work with Linux. In late 2003, Novell announced its purchase of SuSE, a small German Linux vendor, for more than $200 million. IBM invested $50 million in Novell. IBM, Hewlett-Packard, and Dell began to sell hardware with Linux preinstalled. IBM also supports the Mozilla Foundation, developer of the open-source Firefox browser, and with Intel, HP, and other companies recently created the Open Source Development Labs (OSDL), a consortium promoting the business use of Linux, which has hired Torvalds and other open-source developers.

Now, Linux is running on everything from $80 routers to cell phones to IBM mainframes, and is much more common on desktop PCs. Red Hat is a highly profitable $200 million company growing 50 percent per year, and commercial open-source vendors serve many important software markets. For instance, in databases, there is MySQL, which now has annual revenues of about $20 million, doubling every year. In application servers, there is JBoss, and in Web servers, Covalent.

Microsoft achieved dominance by imitating the products of others, copying IBM's PC systems, and cannibalizing the computer industry.

In the server market, the eventual dominance of Linux seems a foregone conclusion. Michael Tiemann, Red Hat's vice president for open-source affairs, told me, "Unix is already defeated, and there's really nothing Microsoft can do either. It's ours to lose." Of course, Microsoft, which refused all interview requests for this article, sees things differently. But surveys from IDC indicate that in the server market, Linux revenues are growing at more than 40 percent per year, versus less than 20 percent per year for Windows. Unix, meanwhile, is declining.

Technologically, Windows and proprietary Unix systems, such as Sun's Solaris, still have some advantages over Linux. But Linux is widely considered to be faster, easier to maintain, and more secure than Windows. As for Solaris, "Sun is very schizophrenic," observed Tiemann. "They're dead, too." Sun recently decided to "open source" Solaris, but most observers feel that that decision has come too late. (Sun, naturally, demurs. "Open sourcing Solaris is a huge step forward," says Simon Phipps, Sun's chief technology evangelist.) When I asked Tiemann whether Microsoft could recover control of the server market if Windows went open source, he said no. "Windows is a proprietary, big-company product," he said. "It isn't modular or clean enough for outsiders to understand or work on, and it's too big."

In the desktop market, Linux's progress is more difficult to gauge. There is sharp disagreement about how quickly open-source operating systems and productivity programs are colonizing PCs. IDC estimates that Linux holds about 3 percent of the global desktop PC market and that its share will double by 2008. Red Hat, Novell, Linspire, and others offer desktop Linux packages, and you can now buy Linux desktops and laptops from many computer retailers, including, interestingly, Wal-Mart. The Firefox browser, which runs on both Windows and Linux, already holds more than 5 percent of the world browser market. And then there is OpenOffice. In one of its quixotic attempts to snap at Microsoft's heels, Sun decided in the late 1990s to purchase and then "open source" a small German competitor to Microsoft Office, just as Linux was starting to destroy Sun's Unix business. OpenOffice runs on both Windows and Linux and, though presently a tiny player, is increasingly being adopted by individuals and businesses worldwide. Conversely, in the last quarter of calendar 2004, Microsoft's revenues from Office and related software declined 3 percent relative to the year before, according to Microsoft's publicly released financial statements.

Of course, Microsoft Office makes use of proprietary document formats, and OpenOffice reads them only imperfectly. (For this article, I sent some documents back and forth between the two suites; no data was lost, but formatting often suffered.) And Linux still lags Windows badly in support for the thousands of peripheral devices available for personal computers, in the number of applications that run on it, and in its ability to work with Palms and Blackberries. But for simple things, OpenOffice works, and its compatibility with Microsoft products is improving.

It is not clear that Microsoft can do anything to stop the open-source encroachment onto the desktop. Many of Microsoft's PC products are now mature. Few users need any additional functionality, and Office exhibits very slow technical progress. Equally importantly, Microsoft has grown heavily dependent upon high prices and forced upgrades for its revenue growth and profitability. But many groups simply cannot afford Microsoft's prices: students, poor people, educational institutions, and the majority of the developing world *(see "South Africa," April 2005, p. 50)*. Microsoft's products now represent a significant fraction of the total cost of a new desktop personal computer. Not only is Linux free or cheap, but because it is smaller than Windows and runs on many more devices, it can run on very inexpensive hardware.

Sensing a power shift, multinational companies and governmental bodies such as the European Union are beginning to insist that Microsoft provide open interfaces—that is, public descriptions of its software that let other programs interoperate with it. China, in particular, is determined to avoid dependence upon proprietary American software. It is concerned about trade disputes, about building its own software industry, and also about vulnerability to "back doors" that could be used for espionage. This last fear is not entirely irrational. Although there are no publicly known cases of espionage against China involving software, other technologies have been so employed. Five years ago China purchased a new, unused Boeing jet and hired U.S. contractors to refit it in Texas as China's equivalent of Air Force One. Upon taking possession of the plane, Chinese security officers found that it harbored more than two dozen highly sophisticated, satellite-controlled listening devices, hidden everywhere from the bathrooms to the headboard of the presidential bed.

Geopolitical paranoia, however, is not the principal reason for the success of open source. The most commonly cited explanation is that evolutionary, decentralized, voluntary efforts can yield better results than those ordered by hierarchical management *(see "Can Technology Raise Society's IQ?" p. 80)*. But while this may be true, there is something even more fundamental at work.

The Open-Source Model versus the Proprietary-Software Industry

Proprietary software is licensed, not sold, with severe accompanying restrictions on copying or modification. This scheme was not devised by fools. It reduces piracy, rewards risk, and allows vendors to enforce compatibility. And when a proprietary vendor controls industry standards, it generates fantastic amounts of money; Microsoft alone has created about ten thousand millionaires through employee stock options. And yet there are now literally thousands of open-source development efforts like OpenOffice, Firefox, Linux, and Apache that have been downloaded tens of millions of times. Why?

Proprietary products cannot be customized by users. Product quality is uneven, in part because outsiders cannot examine source code. If a vendor controls major industry standards, as Microsoft does, it can force customers to upgrade—change to a newer version, and pay more money—almost at will. Furthermore, because lock-in to a proprietary standard is so profitable, imitation is a major threat. Software vendors therefore spend large amounts of money pursuing patents to deter clones and lawsuits by rivals.

Perhaps most importantly, proprietary vendors also treat plans, source code, and technology as secrets that must be carefully guarded. But in software development as in other activities, secrecy allows mistakes and abuses to be covered up. Bad work goes uncorrected; managers hide information to gain career advantage. To ferret out bad work, companies hire testing and quality-assurance groups that are kept separate from development groups, but this is wasteful. And if a software vendor has financial problems or an executive loses an internal political battle, a product can languish for years. If customers have problems, they tell the vendor and hope that it will listen. Sometimes it doesn't, and that's just too bad.

Given its lower growth, Microsoft finds itself a victim of the forces that it once exploited: its costs are fixed and high, while those of Linux are low and declining.

Open source inverts this model. Under the terms of the most common open-source licensing agreement, the GNU General Public License (GPL), a program's source code must be made available whenever the program is distributed. Other programmers may do what they want with it, on one condition: any modifications they make must also be covered by the GPL—that is, their code must be made available. The GPL, in combination with the meritocratic culture of software technologists, has yielded a highly transparent, decentralized approach to software development, controlled by communities of engineers who determine the direction their efforts should take. Open-source development groups generally post all their work publicly, including specifications, source code, bug reports, bug fixes, future plans, proposals for enhancements, and their often vitriolic debates. Linux is open in this sense (and yes, Microsoft monitors it closely).

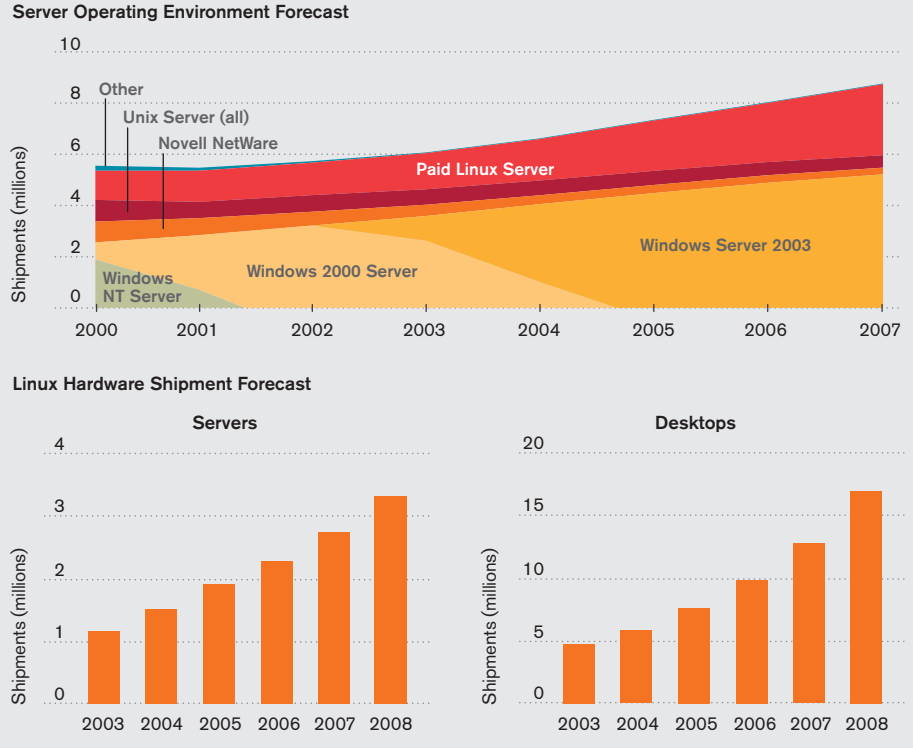
Relative to proprietary efforts, in open-source development there is little management hierarchy, strategic game-playing, patenting, and branding, and few flashy product launch events—in short, less crap. Even though the total Linux workforce is large—as many as ten thousand people—most of it is technical. Red Hat still has fewer than a thousand employees, though it is growing fast. By contrast, Microsoft has 57,000 employees. Microsoft's legal department alone probably costs more money than the governance structure of the entire open-source movement. And there is no question that for many engineers, the comparative absence of crap is one of the major attractions of working on open-source projects—either as volunteers or as paid employees. "We have people lining up to work for us," Red Hat's Tiemann told me. "There are so many people interested in working on open source that we can be very selective."

Furthermore, much of Microsoft's technical workforce must work on quality assurance and bug fixing, which in open-source efforts often come for free from "the community." Given its lower growth rate, Microsoft thus finds itself a victim of the forces that it once exploited: its average costs are fixed and high, while those of Linux are low and declining. Dion Cornett, who does investment research on open source for Decatur Jones Equity Partners, a Chicago-based investment firm, told me, "We estimate Microsoft's development costs for server operating systems, from its public filings, at about $300 per unit. Sun's costs for Solaris are even higher. Red Hat's costs are about $100 per server now, and they'll be under $75 within a year."

Yet open source isn't a perfect production system, either. Its strengths are also its flaws. Sometimes an old-fashioned top-down decision is useful, and the open-source model may not provide sufficient revenue to support everything users want when they want it. BitMover, a vendor of software development tools, used an intermediate model until recently. Its product was free to open-source developers on the condition that they did not use it to develop competing products. For proprietary software developers, it charged normal money. Recently the firm ended the free version, alleging that it had been abused. Larry McVoy, BitMover's founder and CEO, has long been involved with open source, but is nonetheless somewhat skeptical about it. "Microsoft is successful because in open source, nobody gets paid to do the grunt work, like writing boring drivers for every printer on the market," he told me. "Furthermore, open source is largely a copying machine, doing reimplementations of existing products; there's very little innovation, in part because the rewards for it are so low."

There *is* some truth in this. And while the problem is declining as commercial demand for open-source software increases, this creates a final irony. One objection to open source is that, in the end, it might just produce a new generation of big, bad, rich monopolists. With the growing importance of Red Hat, some critics see Microsoft all over again. In an open-source world, one might ask, how could Red Hat possess power in the way that Microsoft presently does? The explanation lies in the premium placed upon compatibility, stability, and service by large corporate customers. Red Hat examines every piece of code it ships; it certifies applications; it ports its code to seven different processor architectures; it provides and tests device drivers; it writes code to improve performance on specific machines; it guarantees service for seven years; it provides the same products in more than a dozen languages; it has someone there to answer the telephone 24-7. Customers who run their businesses on Red Hat won't switch easily, even though a rival's source code is equally available. The code that Red Hat ships therefore becomes, to some extent, the real Linux standard.

Linux Worldwide Market Trends



HARDWARE SHIPMENTS INCLUDE NEW PRODUCTS AS WELL AS PRODUCTS REDEPLOYED AS LINUX MACHINES. SOURCE: IDC

But for all this, Red Hat will probably never wield the same power that Microsoft currently has. One reason is that, because its products are subject to the GPL, other firms can and do take Red Hat's code and sell it themselves.

What the Future May Hold

Given its profound benefits, it is interesting to speculate on how the open-source model might evolve. Many believe that the model can spread to other industries. An obvious possibility is publishing; several interesting experiments are under way, including Wikipedia, an open-source encyclopedia that lets anyone contribute articles or edit existing articles *(see "Larry Sanger's Knowledge Free-for-All," January 2005)*. Another is the Public Library of Science, which provides free refereed scientific journals on the Web that visitors can reproduce or use to make derivative works, provided they credit the original authors. This scheme bypasses the huge, expensive (and phenomenally profitable) proprietary technical publishing industry. Biotechnology and pharmaceuticals are also considered to be fertile areas for open-source experimentation.

Finally, one wonders whether the best features of open source could be combined with the advantages of the proprietary model. One possibility would be to add mechanisms for compensating independent open-source developers. There are interesting precedents. For example, in the music industry, members of the American Society of Composers, Authors, and Publishers receive compensation whenever their work is performed in public or played on the radio or television. Similar compensation rights could be built into open-source code without causing the lock-in problems associated with proprietary software. Vendors and users could choose whether or not to accept code that required compensation; they could rewrite expensive code and replace it; compensation rights could be negotiated, including the possibility of automatically terminating them after a period of time.

Whether this happens or not, there seems little doubt that further evolution will occur. Steve Weber, a political scientist at the University of California, Berkeley, who has studied the open-source industry extensively and consults with IBM and other companies, says, "The model is still very young. There's no doubt that the model will evolve along with the technology and the industry." Its achievements are already impressive, both socially and technologically.

Creators, unite; you have nothing to lose but your suits. ■

Charles Ferguson has a PhD in political science from MIT, where he also completed postdoctoral work and where he will be a visiting scholar this fall. He is the founder and former CEO of Vermeer Technologies, which he sold to Microsoft for $133 million in 1996. Ferguson still holds a substantial quantity of Microsoft stock, a position that is partially but not completely hedged. He also holds a smaller quantity of Red Hat stock, a position that is similarly partially hedged. He has no other financial interest relevant to this article.



Body Image

The latest medical-imaging advances provide unprecedented speed, sharpness, and diagnostic power—and get high points for artistic merit

By David Talbot

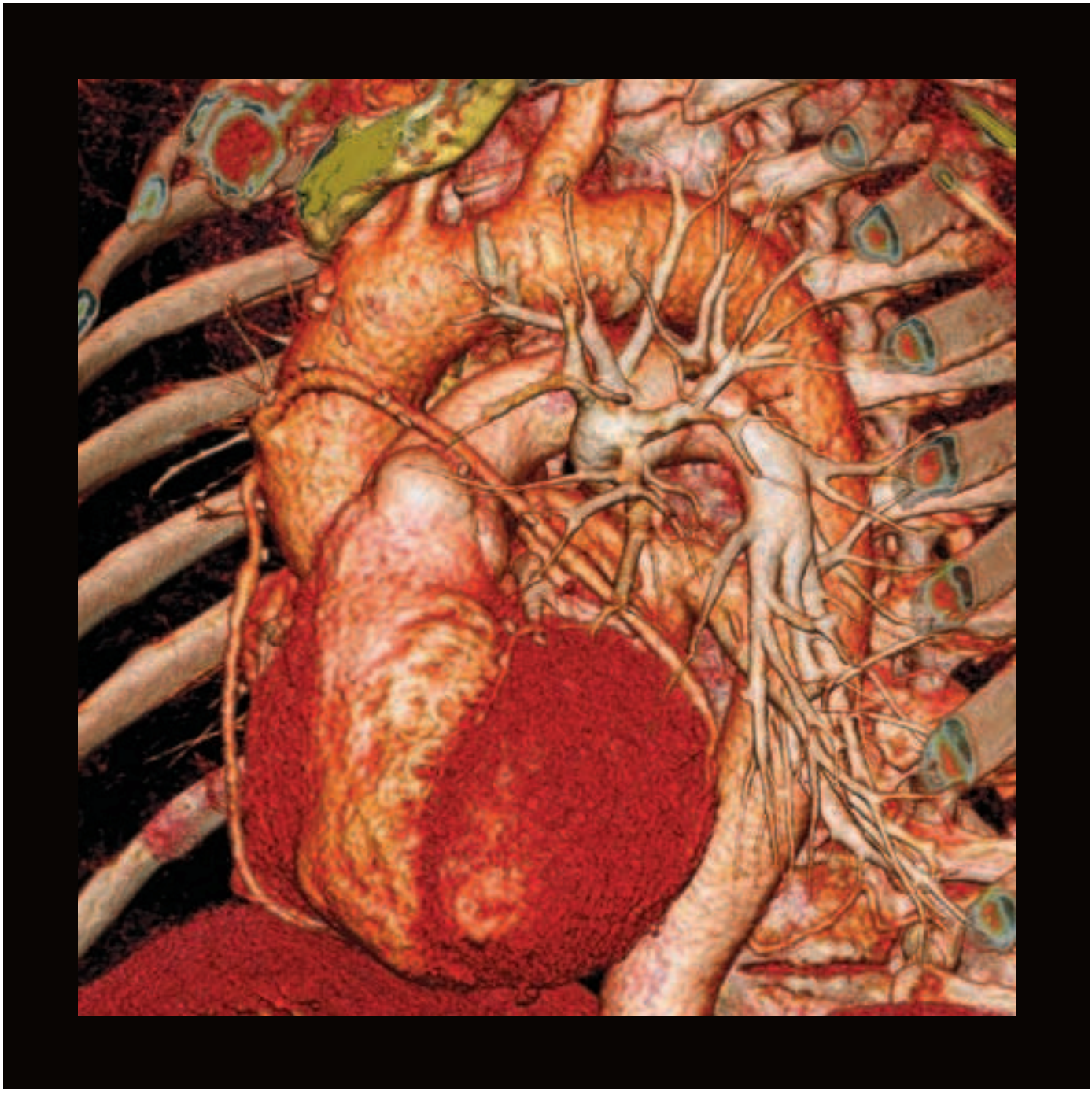


FACING PAGE: A startlingly sharp lung image is made possible by tweaks to x-ray tubes and detector materials in computed-tomography (CT) scanners that resolve features as small as .4 millimeters without sacrificing speed. (Siemens) **THIS PAGE:** Advances in magnetic-resonance imaging (MRI) technology allow a full-body scan to be done in just 12 minutes, without moving the patient. In this image of German swimmer Hannah Stockbauer, anatomical structures were later colorized. (Siemens, Volker Steger)



THIS PAGE: General Electric (GE) says its newest CT scan technology is the world's fastest. It captures images in as little as one second, with resolution sufficient for diagnosing stroke and determining the extent of damage. **FACING PAGE:** Siemens's most recent advance in CT scan technology is reaching market this year. Overlapping x-rays double the resolution for the same scan time, allowing this crisp abdominal image. (University of Munich Hospital, Grosshadern, Germany)







FACING PAGE: A beating heart is captured by a new Siemens CT scan technology that uses overlapping x-rays. Software translates various levels of contrast into colors. (University of Munich Hospital, Grosshadern, Germany) **THIS PAGE:** GE's newest version of CT scan technology captures an image of the heart and coronary arteries in fewer than five heartbeats.

Rise of the Plagiosphere

How new tools to detect plagiarism could induce mass writer's block.

The 1960s gave us, among other mind-altering ideas, a revolutionary new metaphor for our physical and chemical surroundings: the biosphere. But an even more momentous change is coming. Emerging technologies are causing a shift in our mental ecology, one that will turn our culture into the plagiosphere, a closing frontier of ideas.

The Apollo missions' photographs of Earth as a blue sphere helped win millions of people to the environmentalist view of the planet as a fragile and interdependent whole. The Russian geoscientist Vladimir Vernadsky had coined the word "biosphere" as early as 1926, and the Yale University biologist G. Evelyn Hutchinson had expanded on the theme of Earth as a system maintaining its own equilibrium. But as the German environmental scholar Wolfgang Sachs observed, our imaging systems also helped create a vision of the planet's surface as an object of rationalized control and management—a corporate and unromantic conclusion to humanity's voyages of discovery.

What NASA did to our conception of the planet, Web-based technologies are beginning to do to our understanding of our written thoughts. We look at our ideas with less wonder, and with a greater sense that others have already noted what we're seeing for the first time. The plagiosphere is arising from three movements: Web indexing, text matching, and paraphrase detection.

The first of these movements began with the invention of programs called Web crawlers, or spiders. Since the mid-1990s, they have been perusing the now billions of pages of Web content, indexing every significant word found, and making it possible for Web users to retrieve, free and in fractions of a second, pages with desired words and phrases.



The spiders' reach makes searching more efficient than most of technology's wildest prophets imagined, but it can yield unwanted knowledge. The clever phrase a writer coins usually turns out to have been used for years, worldwide—used in good faith, because until recently the only way to investigate priority was in a few books of quotations. And in our accelerated age, even true uniqueness has been limited to 15 minutes. Bons mots that once could have enjoyed a half-life of a season can decay overnight into clichés.

Still, the major search engines have their limits. Alone, they can check a phrase, perhaps a sentence, but not an extended document. And at least in their free versions, they generally do not produce results from proprietary databases like LexisNexis, Factiva, ProQuest, and other paid-subscription sites, or from free databases that dynamically generate pages only when a user submits a query. They also don't include most documents circulating as electronic manuscripts with no permanent Web address.

Enter text-comparison software. A small handful of entrepreneurs have developed programs that search the open Web and proprietary databases, as well as e-books, for suspicious matches. One of the most popular of these is Turnitin; inspired by journalism scandals such as the New York *Times*' Jayson Blair case, its creators offer a version aimed at newspaper editors. Teachers can submit student papers electronically for comparison with these databases, including the retained texts of previously submitted papers. Those passages that bear resemblance to each other are noted with color highlighting in a double-pane view.

Two years ago I heard a speech by a New Jersey electronic librarian who had become an antiplagiarism specialist and consultant. He observed that comparison programs were so thorough that they often flagged chance similarities between student papers and other documents. Consider, then, that Turnitin's spiders are adding 40 million pages from the public Web, plus 40,000 student papers, each day. Meanwhile Google plans to scan millions of library books—including many still under copyright—for its Print database. The number of coincidental parallelisms between the various things that people write is bound to rise steadily.

A third technology will add yet more capacity to find similarities in writing. Artificial-intelligence researchers at MIT and other universities are developing techniques for identifying nonverbatim similarity between documents to make possible the detection of nonverbatim plagiarism. While the investigators may have in mind only cases of brazen paraphrase, a program of this kind can multiply the number of parallel passages severalfold.

Some universities are encouraging students to precheck their papers and drafts against the emerging plagiosphere. Perhaps publications will soon routinely screen submissions. The problem here is that while such rigorous and robust policing will no doubt reduce cheating, it may also give writers a sense of futility. The concept of the biosphere exposed our environmental fragility; the emergence of the plagiosphere perhaps represents our textual impasse. Copernicus may have deprived us of our centrality in the cosmos, and Darwin of our uniqueness in the biosphere, but at least they left us the illusion of the originality of our words. Soon that, too, will be gone. ■

SCOTT MENCHIN

Reviews

Our reviews use any artifact—a book, a product, a government report, a movie, a research paper—as the occasion for a contemplative essay on some technological controversy.

80 Collective Intelligence
82 The Life of Norbert Wiener

Do Maps Have Morals?

Digital mapping is an invaluable tool for business and government—but it's partly rooted in Cold War schemes for mutual annihilation.

BY DANIEL CHARLES

On a snowy morning in early March, looking for the frontiers of digital mapmaking, I hopped into the back seat of an SUV sporting a Global Positioning System receiver on the roof. In front sat two representatives from Navteq, one of the companies that builds the street maps that you see on MapQuest. Phil Satlof, senior geographic analyst, operated a laptop computer hooked up to the GPS receiver.

Looking at the computer's screen, I felt we'd stepped inside a video game. A flashing arrow showed our progress through the familiar grid of Washington's streets. I watched, fascinated, as it marched down a line marked "River Road" into Montgomery County, Maryland.

Half an hour later, in the wealthy suburb of Potomac, the arrow reached the limits of its knowledge. On the screen, the road ended. But our vehicle kept moving, around three new cul-de-sacs in a barren landscape of newly graded dirt, monstrous half-built houses, and yawning holes waiting for foundations. As we drove, the flashing arrow traced our route, expanding Navteq's map of the navigable universe. Satlof added, by hand, what the GPS receiver couldn't see: house numbers, one-way streets, and anything else that pizza delivery drivers may need to know. "We're really a routing company, and as a by-product, we make a map," he explained.

A few hours later and a few miles away, Apollo Teng, manager of Montgomery County's office for geographic information systems, sat down at his computer and retrieved his own map of the area we'd just visited. I saw, once again, those three cul-de-sacs, stretching like fingers toward the Potomac River. Another click of the mouse, and we saw an aerial photograph of the scene, precisely aligned with the street map. Then property lines appeared on the map, as if by magic. When Teng clicked on a property, up came information about its owner, its tax assessment, and its most recent sale. Teng added other features: paths of sewer pipes; areas of protected wetlands; a boundary between watersheds.

Digitizing Our Geography

"American Cartographic Transformations during the Cold War"
By John Cloud
Cartography and Geographic Information Science, July 2002

"The Case of the Missing Overlays"
By John Cloud
A presentation at the German Historical Institute, Washington, DC
October 15, 2004

The History of Geographic Information Systems: Perspectives from the Pioneers
Edited by Tim Foresman
Prentice-Hall, 1997 (out of print)

Environmental Systems Research Institute Map Book Gallery
www.esri.com/mapmuseum/index.html

Teng's database contains more than a hundred different "layers" of information that he can add to the digital map, each layer showing different aspects of the landscape. Any piece of information that comes attached to a street address or latitude-longitude coördinates can slide effortlessly into this visualization: a neighborhood's median income, its history of robberies, even its residents' contributions to political campaigns.

Welcome to the astonishing world of modern mapmaking—what insiders call geographic information systems, or GIS. In fact, it's more than mapmaking. It's a way of organizing information about anything that happens at a particular geographic location. That includes real-estate development, military operations, logging, farming, oil drilling—the list goes on and on. GIS lets companies use mailing addresses to build maps of their customer bases, environmentalists study the effects of climate change on vegetation and glacier movement, and medical researchers in-

vestigate links between contaminated drinking water and cancer incidence. Some devotees of the technology say that it's more than just a useful tool. They call it a new language, one that allows us to understand, and improve, our planet.

The Power of Pictures

The most vocal advocate of the benefits of GIS is also the world's leading seller of GIS software and services: Jack Dangermond, founder and coöwner of a Redlands, CA, company called the Environmental Systems Research Institute (ESRI). (Its motto: "Better decisions through modeling and mapping our world.") Every summer, Dangermond presides over the ESRI User Conference, an international geography jamboree that brings together thousands of digital mapmakers from around the world. ESRI publishes some of the finest work displayed at the conference in a glossy "map book," released annually. In recent years, these books have borne such high-minded titles as *Sustaining Our World* and *Serving Our World*.

This grandiose vision comes from Dangermond himself. "Our science is making a better world for human existence and economic development and arguably could be something that counterbalances everything negative about globalization," he says.

The power of GIS, Dangermond argues, is that it lets us witness the world, from deforestation in the Amazon to crime in local neighborhoods. And having seen what's happening, we can imagine changing it. GIS, Dangermond believes, "will allow us to create a better future."

According to many, digital mapmakers have had an idealistic streak from the beginning. The most comprehensive volume on GIS, *The History of Geographic Information Systems*, opens with an essay by landscape architect Ian McHarg, who advocated "transparent-overlay maps" in the 1960s as a way for planners to see more clearly the aspects of nature—forests, wildlife, and marshes—that new roads and buildings would obliterate.

Those physical overlay maps inspired a generation of environmentalists, including Dangermond, who studied landscape architecture at Harvard University. The idea of creating maps from layers of data became the heart of GIS, and it's the secret of its power. Using software like Dangermond's, people could combine census information, satellite photos, and many other types of data to reveal relationships that were never obvious before.

At first glance, the value of GIS seems self-evident. It's hard to imagine a more innocent and enlightening technology than a map. Maps reveal the truth about our world, and the truth, as the saying goes, will set us free. Or will it?

Nazis, Soviets, and Software

I slide a copy of *The History of Geographic Information Systems* across the table toward historian John Cloud, and he recoils as if it were something toxic. "The enemy," he mutters with a twisted smile, only partly joking.

Cloud considers this book a "cover story," a misleading history that gives university-based scientists more credit for GIS than they deserve. The *real* roots of digital mapping, he says, reach back to the Cold War and to the U.S. Defense Department's secret campaign to assemble accurate maps of nuclear targets in the Soviet Union.

Before taking his current job as a historian for the National Oceanic and Atmospheric Administration, Cloud spent more than a decade assembling an alternative genealogy of GIS, showing military planners, not idealistic landscape architects, to be its fathers. In the 1950s, the Defense Department recruited scientists to determine the exact distances between the earth's continents—essential for aiming intercontinental ballistic missiles. Later, Pentagon officials sent the first remote-sensing satellites aloft to photograph "denied territories" inside the Soviet Union. In the 1960s, the Pentagon converted those images into digital data, and in the 1980s, the U.S. Air Force launched the Global Positioning System, the essential tool for today's mapmakers.

These military projects were the pillars on which geographic information systems were built, Cloud says. In scale and sophistication, they dwarfed anything accomplished in the civilian world at that time. And the world imagined in these maps was not one of environmental sustainability but one of nuclear war.

As for Ian McHarg's transparent-overlay maps, intended to help preserve nature and facilitate more-livable cities—well, that, too, is a nice-sounding cover story, says Cloud. There were other forerunners of layered digital maps, he says, including some that were used for less uplifting purposes than McHarg's.

Searching through archives and old cartography publications, Cloud found several overlay maps from the 1930s and 1940s. They were, he says, "the most complex and accomplished uses of overlays yet found." One set, prepared by federal officials during the New Deal, depicted American cities and showed, with different translucent layers, data about problems such as high concentrations of decrepit buildings. Later maps, concealed for many years from public view, carried fateful red lines that enclosed blocks occupied mainly "by any distinct racial, national, or income group that would be considered an undesirable element if introduced into other parts of the city," in the words of a 1936 document cited by Cloud. Thus was born the term "redlining" (say, charging residents of targeted areas more for loans or insurance). Yet Cloud has found no evidence that others adopted these innovative mapmaking techniques and applied them more widely. Apparently, they were used and then abandoned.

While interviewing Lawrence Ayers, former deputy director of the U.S. Defense Mapping Agency, Cloud learned of another set of overlay maps that may have fallen on more-fertile ground. The maps were created by the German military during World War II and captured by American forces near the end of the war. They were composed of transparent sheets—sometimes 20 or more—showing such things as vegetation, soil, and road surfaces. According to Ayers, the Defense Department's own mapmakers quickly saw the value of this technique and adopted it themselves, first applying it to physical maps, then to digital sets of data. "The concept of the overlay is what the software writers picked up and used to take advantage of digital technology," says Ayers. "It goes back to the Germans."

Ayers and Cloud make an odd pair of allies. But the two of them—one a retired defense official and corporate executive, the other a sandal-wearing former academic and environmental activist—agree the Defense Department laid the foundations for



This digital map, created for emergency planners in Berkeley, CA, predicts fallout-related fatalities from a hypothetical nuclear attack on the San Francisco peninsula. It is based on 2000 census data and actual weather patterns recorded on July 4, 2003.

BRIAN B. QUINN, GIS DIVISION, CITY OF BERKELEY, CA

what's now called GIS. It created the earliest digital maps, and its contracts "pumped money," as Ayers puts it, into several companies that now play leading roles in the GIS industry.

Showing the Way

Some historians and GIS pioneers, however, dismiss this version of GIS history with a mixture of irritation and disdain. Nicholas Chrisman, from Laval University in Québec City, says the Pentagon produced little, apart from the Global Positioning System, that the commercial world ever found useful. And none of the early developers of GIS software even knew about the physical overlay maps of the New Deal or the Nazi era, he says, while they certainly *did* know about McHarg's. ESRI's Dangermond, for his part, says his company knew little about the military's work and profited even less from it.

The Pentagon didn't invent the entire field of GIS, as Clark implies. Yet his search for the dark, hidden ancestors of modern mapmaking illustrates something simple and true: maps—like technological progress itself—are not inherently benevolent.

Even Dangermond, when pressed, concedes the point. "I'm not political about *how* technology gets used. It gets used," he says. "My own interest was obviously in the area of environmental things. But it gets used by everybody."

The consequences of those uses vary. Six months ago, relief workers used digital maps to find their way through areas devastated by the Indian Ocean tsunami. The U.S. Air Force relies on such maps in Iraq. Aerial photographs and digital mapmaking tools are allowing the governments of Uruguay and Brazil to survey and sell off vast tracts of land. "Sitting there in Arlington, Virginia, you can buy land in Brazil," says Christopher Simpson, a professor of communications at American University in Washington, DC, who's been studying current uses of remote sensing in Latin America. In theory, Brazilian peasants can buy the land they currently till. But in practice, Simpson says, the best properties will be snapped up by "those with the most resources, who are best organized, with the best overview." In other words, those with access to digital maps of millions of unclaimed acres.

Geographic information systems extend the reach of the human imagination, but in the end, they mainly help people do what they wanted to do in the first place. They're tools for preserving nature or destroying it, for defending human communities or obliterating them, for empowering or impoverishing. Maps can show us the way, wherever we choose to go. ■

Daniel Charles reported on technology for National Public Radio and wrote Master Mind: The Rise and Fall of Fritz Haber, the Nobel Laureate Who Launched the Age of Chemical Warfare.

Group Rethink

Can technology raise society's IQ?

BY MICHAEL FITZGERALD



Common sense is uncommon in individuals and, at first blush, seems even more so in groups. No one expects crowds to produce useful thought. We fear the tyranny of the majority and mob rule, avoid peer pressure where we can, and immediately see the aptness of Charles Mackay's 19th-century book title *Extraordinary Popular Delusions and the Madness of Crowds*

But the idea of collective intelligence shouldn't seem so farfetched. After all, democracy is built on the principle that large groups know how to govern themselves. Commodities markets, which set prices on the basis of group knowledge, play a growing role in everyday business decisions. Even lone geniuses build on the work of others: for every Einstein there are Poincarés and Lorentzes and Hilberts lurking in the background.

In fact, evidence of collective intelligence is all around us, and *New Yorker* writer James Surowiecki collects much of it in *The Wisdom of Crowds*. [Surowiecki wrote on technology and happiness for the January 2005 issue of *Technology Review*.] Surowiecki shows how groups can often outthink even the most knowledgeable experts. He offers proof after proof that "the value of expertise is, in many contexts, overrated." By recounting how the stock market divined that booster rocket manufacturer Morton Thiokol was most to blame for the *Challenger* shuttle disaster (the official answer came six months later), or how the U.S. Navy found the sunken submarine *Scorpion* by aggregating the best guesses of a variety of experts, Surowiecki demonstrates that collective intelligence can be harnessed, and that it does not have to be unwieldy. Collections of experts, he concedes, are prone to the ills of groupthink, which can lead to debacles like the Bay of Pigs. But he argues that crowds with certain characteristics—notably, diversity of opinion, independence of opinion, decentralization, and a way to aggregate opinions to arrive at a collective decision—will generally outsmart their most brilliant members. This is true for specific problems and broad ones, Surowiecki says, and for crowds big and small. His premise quickly comes to seem intuitive.

Groups, then, can act as parallel-processing decision engines, pooling disparate knowledge to answer even hard questions in areas like public policy. What we lack, however, is a reliable way to build such decision engines. And Surowiecki's book, unfortunately, offers no practical solutions.

But technologists, entrepreneurs, and venture capitalists do. The last several years have seen intense interest in developing technology that improves our connectedness *(see "Tagging Is It," p. 21)*. In part, that interest was spurred by the phenomenal success of open-source software, which is built by communities *(see "How Linux Could Overthrow Microsoft," p. 64)*. It also reflects the success of Google and eBay, which have profited by harnessing the collective behaviors of very large groups. Connecting technologies like online social networks and Web logs, or "blogs," are familiar to many people, and wikis—group Web pages that any member may edit—soon will be *(see "Larry Sanger's Knowledge Free-for-All," January 2005, p. 21)*. Technologists, then, are already attacking the problem of how to achieve a high group IQ.

Better communications tools are one ingredient. Indeed, Thomas W. Malone of MIT's Sloan School of Management argues in *The Future of Work* that ever cheaper and more-useful communications technology will effect a revolution in the way businesses operate. E-mail is the obvious example, but Malone

MATT DENNIS

Collective Intelligence

We the Media: Grassroots Journalism by the People, for the People
By Dan Gillmor
O'Reilly, 2004, $24.95

The Future of Work: How the New Order of Business Will Shape Your Organization, Your Management Style, and Your Life
By Thomas W. Malone
Harvard Business School Press, 2004, $29.95

The Wisdom of Crowds: Why the Many Are Smarter than the Few and How Collective Wisdom Shapes Business, Economies, Societies, and Nations
By James Surowiecki
Doubleday, 2004, $24.95

The Revolution Will Not Be Televised: Democracy, the Internet, and the Overthrow of Everything
By Joe Trippi
ReganBooks, 2004, $26.95



also points to artificial electronic markets, which can aggregate employees' best guesses about sales, resource allocation, research and development efforts, and even pollution control. That last was done at BP, which used an internal futures market rather than a committee of experts when it wanted to find ways to reduce its emissions.

Malone says such markets, combined with blogs and other technologies that make it easier for employees to share information, will enable, for the first time in business history, "the economic benefits of large organizations, like economies of scale and knowledge, without giving up the human benefits of small ones, like freedom, creativity, motivation, and flexibility." He is convinced that companies like Google, which uses internal blogs to keep management ranks flat, represent the future of industry. Tomorrow's companies, he predicts, will be led not by dictatorial, alpha-ego CEOs but by "cultivators" who understand that productivity and profits soar when all of a company's intellectual capital is being tapped.

Other institutions are also being remade through technologies that marshal collective intelligence. Dan Gillmor's *We the Media* shows how blogging, the Short Message System (SMS), and corollary technologies like Really Simple Syndication (RSS) are creating a new and vital kind of journalism. (In the interest of full disclosure, I should mention that I am friendly with Dan.)

Gillmor believes that such technologies have brought us to a turning point in media history: with the removal of major barriers to information distribution, such as the need for a broadcast license or a printing press, more people can provide journalistic observation, and that makes for a better-informed populace.

It can also make for better media. An excellent illustration involves *Jane's Intelligence Review*, the respected defense periodical. In 1999, *Jane's* posted a draft of an article on cyberterrorism to the massively popular online discussion forum Slashdot, whose denizens vetted the document so thoroughly that *Jane's* decided to rewrite it from scratch.

Gillmor does not claim that blogging, SMS, and the like are perfect. He is concerned about the ease with which technology can be used to promulgate untruths (he remembers the faked picture of John Kerry with Jane Fonda at an anti-Vietnam rally). He worries about "trolls" (people who post disingenuous, irrelevant, or obscene messages in order to get attention) and "spin doctors" (people who deliberately post misleading items). But he explains how the communal character of blog culture mitigates many potential excesses: bloggers who are uninteresting don't get linked to; those who make false assertions can be pilloried. What frightens him more is the prospect that governments and the mainstream media will try to slow or even derail bloggers, SMS news services, and other emergent forms of journalism through defamation or copyright infringement laws.

Like many, Gillmor also believes that networked technologies could make the political process more democratic. For at least a decade, the Internet has been hailed as the antidote for big campaign contributors' undue influence on electoral outcomes. Until recently, it was a quack cure. But the Howard Dean campaign's successful use of the Internet in the 2004 Democratic primary race suggests that, as Gillmor puts it, "American politics was approaching a tipping point." Joe Trippi, Dean's former campaign manager, agrees.

In his book *The Revolution Will Not Be Televised*, Trippi contends that the Dean campaign would never have taken off had he not employed communications technology like Meetup, a website that facilitates real-world gatherings. He argues that in 2004, the Internet was to the presidential election what television was in 1956—something present in 75 percent of homes but not truly understood by most politicians and political operatives. But by 2008, Trippi says, the Internet will be at the heart of the political process. America, in Trippi's view, is now run by the 631 people who collectively raised between $100 million and $150 million for the Bush campaign. But technology will make it possible for ordinary citizens to band together, piling small donations into substantial political war chests and speaking with a voice every bit as powerful as those of the special-interest lobbies. The model for all this? The campaign of Howard Dean, of course.

What Trippi identifies as the Dean campaign's strength could just as easily be described as its main problem: it was propelled by its supporters and therefore had no strategy for directing, or even much understanding of, the forces it had unleashed. The campaign had no clue, Trippi makes clear, that thousands of people would show up at Dean meetups at a time when the candidate was barely mentioned in the national press. Nor did it expect to see millions of dollars in small contributions coming in via the Internet.

Yet it's beguiling to envision campaigns that are shaped as much by voters as by the candidates themselves. Trippi seems to be that rare political professional who would be happy to find that, in the next campaign cycle, he was out of a job.

An influence upon all these books is Howard Rheingold's *Smart Mobs*, which looked at the way groups of people use cell phones and other wireless devices to organize collective action. Rheingold wrote that "the most far-reaching changes will come...from the kinds of relationships, enterprises, communities, and markets that the infrastructure makes possible."

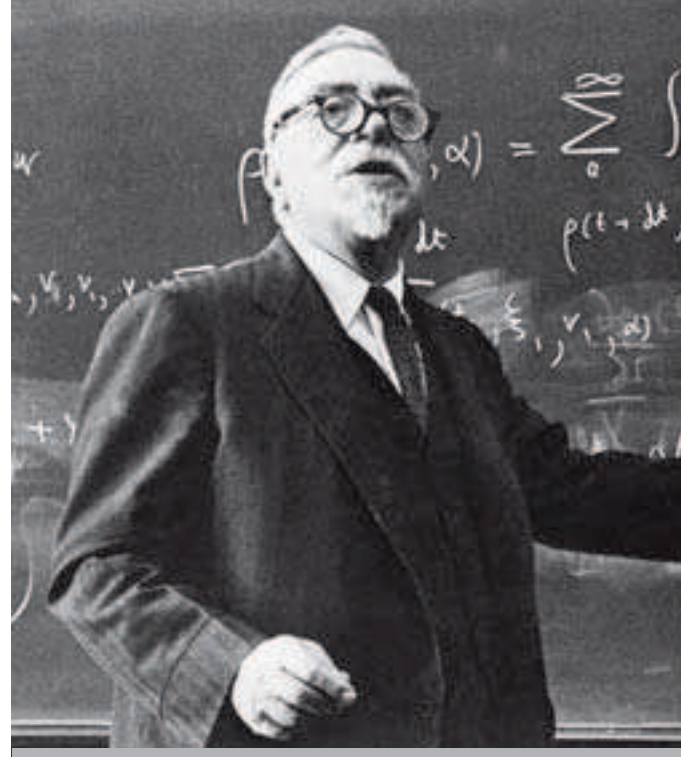
Creating a communications infrastructure that fosters a healthy democracy has been a concern of the United States since its founding. Newspaperman and intellectual Walter Lippmann once noted that the real trouble with both the press and representative democracy is "the failure of self-governing people to transcend their casual experience and their prejudice by inventing, creating, and organizing a machinery of knowledge." That machinery may finally have arrived. ■

Michael Fitzgerald is a writer who lives outside Boston. He writes frequently for Technology Review, *and his work has appeared in the* Economist, *the New York* Times, *and other publications.*

Cybernought

The founder of cybernetics is largely forgotten. That's a pity

BY MARK WILLIAMS



No Mean Mathematician

Dark Hero of the Information Age: In Search of Norbert Wiener, the Father of Cybernetics

By Flo Conway and Jim Siegelman

Basic Books, 2004, $27.50

THOUGH NORBERT WIENER was one of those 20th-century illuminati who ushered humankind into the age of intelligent machines, few people today know much about him. So whatever prompted Flo Conway and Jim Siegelman to write *Dark Hero of the Information Age: In Search of Norbert Wiener, the Father of Cybernetics*, it wasn't any expectation of a bestseller. Wiener is past all likelihood of rescue by fashion. The authors must simply have been drawn to their subject by one of those virtuous impulses that are their own reward.

Dark Hero, Conway and Siegelman claim, was "eight years in the making and a dozen more in the planning." Alas, while their hearts may be in the right places, these authors turn out to be unable to think deeply or write well. Here, for instance, is the book's fourth paragraph: "This is the story of a dark hero who has fallen through the cracks in the information age and of his fight for human beings that is the stuff of legend." Things don't improve after that. For some months, however, *Dark Hero* may provide fodder for columns like this one. So while this inadequate book provides the occasion, let us seize it.

Let us recall the thought and life of a man who, though not conventionally heroic—since he was short, stout, myopic, physically clumsy, and so socially maladroit that he could pick his nose while delivering a lecture—nevertheless combined brilliance with such determination to behave ethically that those who know his work or writing still feel fond admiration for him.

Both Norbert Wiener's greatness and his flaws were tied to his lifelong sense of himself as an outsider. In particular, he bore the burden of having been a child prodigy. Born in 1894, Wiener entered Tufts University to study mathematics at 11, graduated at 14, and proceeded to Harvard University, completing a dissertation in mathematical logic at 18. Thence, he embarked for Europe for postdoctoral study under Bertrand Russell and the mathematicians G. H. Hardy and David Hilbert.

In 1919, at 24, Wiener joined the MIT mathematics faculty. In the 1920s, he provided a mathematical description of Brownian motion—the arbitrary movement of microscopic particles suspended in a liquid or gas. Albert Einstein, in one of his seminal 1905 physics papers, had attributed Brownian motion to random collisions between the suspended particles and molecules in their environment. By marrying Einstein's work with that of French mathematician Henri Lebesgue, Wiener was able to describe the probability with which any of the particles would follow a particular trajectory. His work yielded the so-called Wiener measure, which has since found practical applications in many branches of physics, engineering, and biology.

During World War II, Wiener made a brilliant contribution to the science of fire control for antiaircraft guns—essentially, the computation of a fast-moving aerial target's future position. Building on his prior work on the statistical description of trajectory, Wiener produced probabilistic equations that, embodied in crude World War II–era analog electronics, could translate radar information about a target's motion and distance into a prediction of its flight path and automatically swing a gun in the right direction. To improve the gun's aim, engineers relied on a "feedback loop": a reading of the gun's position was converted into an electrical signal, which was compared with the original command signal. The gun was then moved to close the difference. The implications of this technique weren't lost on Wiener.

Today, self-correcting mechanical systems surround us. So it's hard for us to appreciate the impact of Wiener's ideas in the mid-20th century, when he pointed out the similarity between machines with sensory systems that collected information to fine-tune their behavior and biological systems—like human beings—that did the same thing. Cybernetics—Wiener's theory of "control and communication in the animal and the machine"—made him a cultural figure prominent enough to be featured in *Time* magazine cover stories.

After 1945, Wiener opposed the military-industrial complex's increasing influence on scientific affairs. As a result, he became estranged from many of his colleagues and from developments in automation and computer technology. "So long as we retain one trace of ethical discrimination, the use of great powers for base purposes will constitute the full moral equivalent of sorcery and simony," he wrote in 1963, the year before his death. Norbert Wiener believed that scientists and technologists had an ethical responsibility both to the truth and to humanity; through all his life, he attempted to meet the terms of that contract. ■

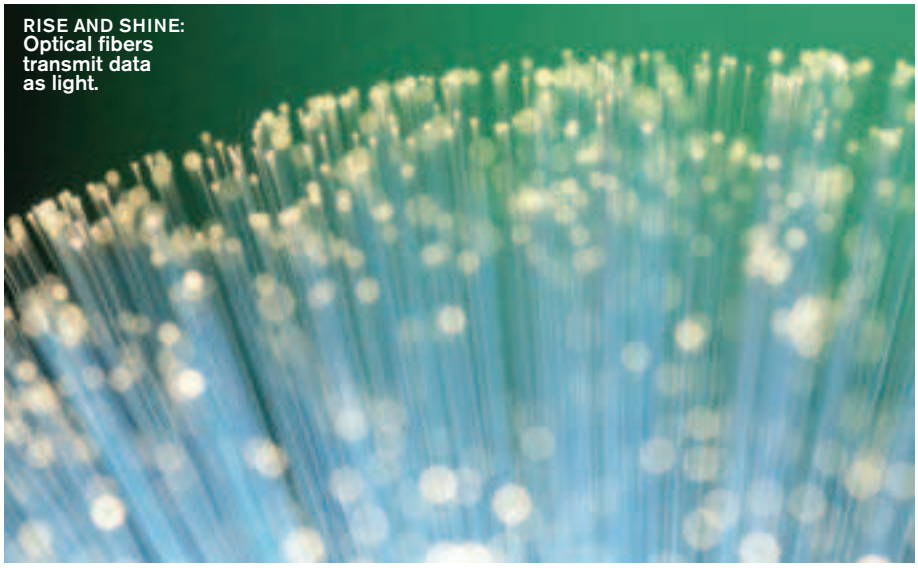
Mark Williams is a writer who lives in Oakland, CA.

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From the Lab

EDITED BY MONYA BAKER

Each month brings new investigative tools, new ideas for revolutionary technology, and revolutionary applications of existing technology. No one can know today which will matter most tomorrow. But these represent *Technology Review*'s best prediction.



RISE AND SHINE: Optical fibers transmit data as light.

GEORGE B. DIEBOLD/CORBIS

INFORMATION TECHNOLOGY

Light Speed

Faster optical networks from slower light

CONTEXT: Optical fibers cross cities and oceans and form the backbone of much of the world's high-speed data communications network. But the throughput of optical fiber is limited by how fast data can be switched across networks. In a conventional router, light from fibers must be converted into an electrical signal, switched to an appropriate cable, then converted back to light again; this process can slow the speed of information transfer by a factor of ten. A router that did not need to use an electrical signal would be inherently faster. But the electrical signals are necessary to hold data intact until the optical switch to the next cable is ready. A team of scientists from the École Polytechnique Fédérale de Lausanne in Switzerland has demonstrated a novel way to slow down light in an optical fiber, so that switching from cable to cable can be coördinated with light signals instead of electricity.

METHODS AND RESULTS: The speed at which light travels through different physical media is not constant; light interacts with the matter it passes through, and this interaction can slow it down ever so slightly. Kwang Yong Song and colleagues fired an intense laser down a standard telecommunications fiber, causing atoms in the fiber to vibrate. If an optical signal is sent from the fiber's other end, the light interacts with these moving atoms more than it would with unperturbed ones, and it slows down by tens of nanoseconds along several kilometers' length of fiber. Critically, the light's speed in the fiber can be easily modulated: the more intense the laser, the more the atoms move, and the more the optical signal is delayed.

WHY IT MATTERS: The Swiss team is not the first to slow down light, but its experiments are notable for how they might affect the telecommunications industry. The new technique makes all-light routers feasible and could boost throughput from existing optical networks several-fold. That might enable scattered computers to link together seamlessly into a networked supercomputer, for instance. The method also works in standard optical fibers, making it compatible with existing telecommunications networks.

Source: Song, K. Y., et al. 2005. Observation of pulse delaying and advancement in optical fibers using stimulated Brillouin scattering. *Optics Express* 13:82–88.

Debabbling

Isolating speech signals in audio recordings

CONTEXT: Microphones placed around a meeting room tend to yield recordings where voices overlap and are hard to distinguish. When there are at least as many microphones present as people talking, computer algorithms have been able to isolate the audio of each speaker. But if fewer microphones are used, these methods don't work, and problems of voice overlapping can persist. Alternative methods require creating a profile of each speaker's voice from previous recordings or making certain assumptions about the audio signals. Now Francis Bach and Michael Jordan of the University of California, Berkeley, have developed an algorithm that separates the voices of multiple speakers in recordings made with just one microphone, without requiring strong prior assumptions or speaker profiles.

METHODS AND RESULTS: Bach and Jordan's algorithm homes in on the voice characteristics that are most likely to vary among people. The recorded sounds are laid out in a spectrogram, which shows the intensity of sound of various frequencies over time in a two-dimensional graph. Bach and Jordan's algorithm automatically divides up the spectrogram among the speakers; it assumes that parts of the spectrogram are likely to be from the same speaker if they are near each other on the graph, vary similarly over time, or are alike in pitch and timbre. The algorithm is trained on samples in which separately recorded voices have been mixed; based on the training, the algorithm assigns a relative importance to each characteristic—say, timbre or tempo. Then the algorithm applies this training to new recordings. So far, the authors have been able to separate the overlapping voices in several recordings of pairs of speakers. Although the separation is not perfect, both speakers are more intelligible.

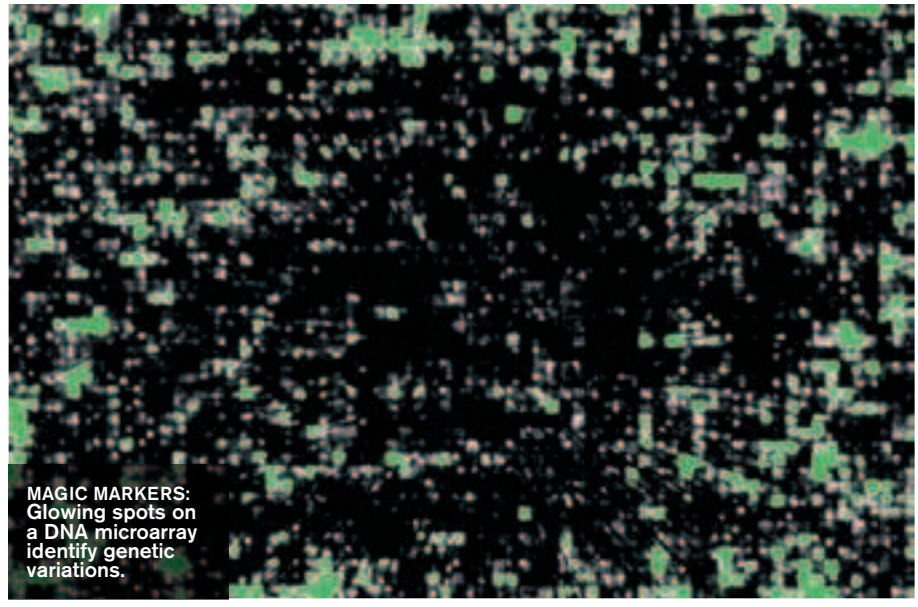
WHY IT MATTERS: Historians, journalists, lawyers, and other professionals rely on recorded conversations. These recordings are often made using a single microphone but feature multiple voices. By making babble more comprehensible, Bach and Jordan's algorithm promises to make such recordings more useful and easier to analyze. Hence, users may no longer be forced to haul around bulky, expensive equipment when recording important conversations and events.

Bach, F. R., and M. I. Jordan. 2005. Blind one-microphone speech separation: a spectral learning approach. *Advances in Neural Information Processing Systems* 17 (in press).

BIOTECHNOLOGY

Gene Map Shortcut

Using fewer markers to capture genetic variations



MAGIC MARKERS: Glowing spots on a DNA microarray identify genetic variations.

COURTESY OF DAVID HINDS/PERLEGEN

CONTEXT: The Human Genome Project provided a parts list of our genes, but that alone cannot connect genetic variants with health; diseases and drug responses must be correlated with genetic markers that vary from person to person. The most common and easily assessed markers are single-nucleotide polymorphisms (SNPs), in which genetic sequences swap one DNA "letter" for another.

But an individual has many more SNPs than researchers can afford to measure, and until now, there have been no reliable tools for selecting the most representative ones. Recently, the biotech company Perlegen Sciences and its collaborators at the International Computer Science Institute and the University of California, San Diego, completed the first map of SNPs that provides these tools. This map will move us closer to an era in which patients' genetic makeup routinely guides their medical treatment.

METHODS AND RESULTS: To figure out which SNPs are most informative, researchers at Perlegen needed to know how frequently particular SNPs occur in a population and which ones are most likely to occur together. Led by David Cox, the researchers selected SNPs that represented all 46 chromosomes and whose least-frequent versions still occurred in 1 to 5 percent of individuals. Each occurred at least once in 71 volunteers identified as being of African, European, or Han Chinese ancestry; the researchers kept track of who had what SNPs and which ones were likely to occur together in each population. Overall, Perlegen studied nearly 1.6 million SNPs. The researchers compared their data with that from other studies of much smaller sections of the genome, where nearly all of the so-called common SNPs have been found. That comparison revealed that the SNPs that Perlegen studied could be used to predict the occurrence of most others that were not in its set of 1.6 million. In other words, the researchers found that studying a subset of SNPs captures most of the information about frequently occurring variations. They also found that the subset of common SNPs varied slightly among different ethnic groups.

WHY IT MATTERS: The Perlegen study shows that future genetic-variation studies might be easier and cheaper than previously thought. Because so many SNPs are correlated with each other, studies that measure fewer SNPs can potentially get results as powerful as those that measure many more, and the map the researchers created will help epidemiologists select SNPs to study.

A second map of SNPs, which surveys more people, is due out from the International HapMap Project later this year. The two maps will complement each other. For now, Perlegen has shown that these maps can be made and could provide a powerful tool to link genetic variations with disease and medicine.

Source: Hinds, D. A., et al. 2005. Whole-genome patterns of common DNA variation in three human populations. *Science* 307:1072–1079.

Out with the Bad, in with the Good

Therapy silences disease gene, adds healthy one

CONTEXT: The usual goal of gene therapy is to supply missing instructions for creating a protein. A newer kind of gene therapy instead short-circuits problematic instructions. Supplying the missing protein has shown both promise and problems: it cured children of severe combined immunodeficiency, a rare genetic disease, but has also led to fatal leukemia and toxicity. The second approach improved symptoms in mice suffering from a disease similar to Huntington's but is not yet ready to try in humans. If it proves safe, a more versatile option may be to combine both approaches, suppressing a problematic protein while creating a therapeutic one. That's what Patrick Aebischer's team at the École Polytechnique Fédérale de Lausanne in Switzerland has done for a mouse with the rodent version of Lou Gehrig's disease.

METHODS AND RESULTS: Amyotrophic lateral sclerosis, or Lou Gehrig's disease, kills muscle-controlling neurons; patients eventually become paralyzed and die. In some cases, mutations in a gene called SOD1 are responsible. Mice engineered with a mutant version of human SOD1 have trouble walking, breathing, and grooming themselves and eventually die. To silence this problem-causing gene, Aebischer's team used a technique called RNA interference (RNAi). In RNAi, short strands of RNA match up with a gene's messenger RNA, destroying it before it can take part in protein assembly. The researchers inserted instructions for RNA targeting SOD1 into a genetically modified virus. Then they injected the virus into mice. RNAi suppressed the mutant human SOD1 gene but ignored normal mouse SOD1. Though the treated mice still got sick and died, they remained healthy longer. However, in humans, RNAi would likely silence not just the mutant version of the SOD1 gene but also the healthy version. So Aebischer's team genetically engineered a virus to deliver both instructions for RNAi and a gene for human SOD1 designed so that it would not be shut down by RNAi. Though the new virus has so far been tested only in cells, it is the first demonstration of a promising new technique.

WHY IT MATTERS: Aebischer's technique could overcome a nagging limitation of RNAi. Particularly for diseases like Lou Gehrig's, which can be caused by many different mutations in a particular gene, RNAi cannot be engineered to attack the disease-causing form of a gene without attacking its normal counterpart. By designing genes unaffected by RNAi and delivering them alongside instructions to silence the existing gene, Aebischer's team has found a general way to use the technique against diseases in which the nontargeted gene must remain functional.

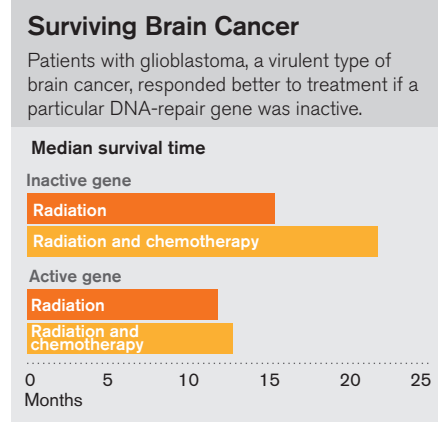
Source: Raoul, C., et al. 2005. Lentiviral-mediated silencing of SOD1 through RNA interference retards disease onset and progression in a mouse model of ALS. *Nature Medicine* (published online).

Better Hope for Brain Cancer

More-effective chemo, and who should get it

CONTEXT: Patients diagnosed with glioblastoma, a particularly malicious kind of brain cancer, rarely live much longer than a year, even with surgery and radiation therapy. Chemotherapy seems to help some patients but not most. Now, in a large clinical trial, teams led by Roger Stupp and Monika Hegi at the Centre Hospitalier Universitaire Vaudois in Switzerland and the European Organisation for Research and Treatment of Cancer have identified a more-effective form of chemotherapy and a way to single out which patients are likely to benefit from it.

METHODS AND RESULTS: Patients were randomly assigned to receive radiation either on its own or combined with a drug called temozolomide, which damages DNA. On average, patients receiving the drug lived about 10 weeks longer than patients who did not, a benefit that has been considered significant enough to warrant the approval of other cancer drugs. (In fact, in March, the U.S. Food and Drug Administration approved temozolomide for treating glioblastoma.) When possible, the researchers also examined a DNA-repair gene in patients' tumors to see if it had been silenced by a so-called epigenetic modification, which alters gene expression without changing a gene's sequence. In healthy cells, such silencing is often one of the first steps toward cancer. Ironically, however, the silenced gene repairs the very damage caused by temozolomide. The results were striking: patients with silent DNA-repair genes who received temozolomide and radiation lived nine months longer



than patients with active genes who received the same treatment. In fact, in cases where the DNA-repair gene was active, patients who received combination therapy did not live significantly longer than patients receiving radiation therapy alone.

WHY IT MATTERS: Chemotherapy makes people feel sick, and physicians are loath to prescribe it when it is unlikely to help a patient live longer. However, in the United States, chemotherapy is often prescribed even if it has only a slight chance of extending life. Stupp and Hegi's results show not only an effective therapy but also a way to pinpoint those patients most likely to benefit from it. The study also illustrates the need to improve the ease of genetic tests, particularly those that look for problems with gene expression rather than changes in DNA sequences. The researchers could tell whether a DNA-repair gene was silent in only 67 percent of the patients for whom tumor material was available,



Max Stührling's big mistake

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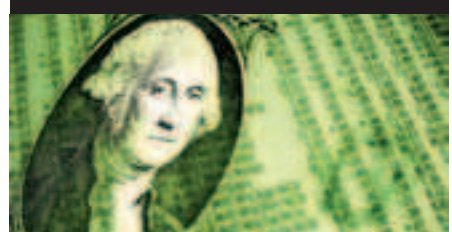
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because some tumor samples were of poor quality. With such a promising way to detect which patients should get chemotherapy, researchers need better ways to collect and store samples, as well as tests that work with ill-preserved samples.

Sources: Stupp, R., et al. 2005. Radiotherapy plus concomitant and adjuvant temozolomide for glioblastoma. *New England Journal of Medicine*352: 987–996.

Hegi, M. E., et al. 2005. MGMT gene silencing and benefit from temozolomide in glioblastoma. *New England Journal of Medicine*352:997–1003.

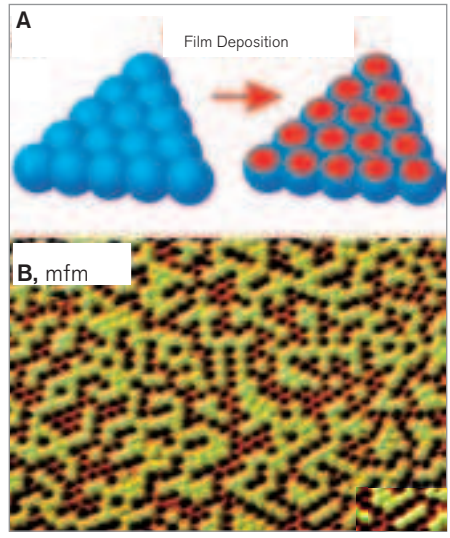
NANOTECHNOLOGY

Shrinkable Storage

Capstone in magnetic hard-disk design

CONTEXT: In a hard drive, each bit of information is written on magnetic grains inside a hard disk. Engineers have so far squeezed more data into smaller media by using fewer and fewer grains to hold each bit. But hard-disk manufacturers are now up against physical limits on how much their grains can shrink before they become unstable and lose data. Recent work by researchers from the University of Konstanz in Germany and Hitachi reveals a new magnetic medium that could be the basis for the hard drive of the future.

METHODS AND RESULTS: Manfred Albrecht and colleagues created their hard-disk medium by first putting down a layer of closely packed nanoscale latex spheres. By sprinkling atoms of cobalt and palladium onto the spheres, they created "magnetic caps" that can store a binary digit as the polarity of a magnetic field. But while its polarity can be flipped, the field always remains perpendicular to the thickest part of the caps. So when the cobalt and palladium rain down onto the spheres from directly above, the magnetic field is perpendicular to the disk surface, as in today's most advanced hard drives. By orienting the layer of spheres at a 45-degree angle to the stream of cobalt and palladium, the authors created a medium



MAGNETIC BITS: A, diagram of latex nanospheres with magnetic "caps." B, image of new hard-drive material from magnetic force microscopy (MFM).

that should be more responsive to magnetic fields from a recording head. This could allow manufacturers to use materials that are magnetically more stable than those in conventional hard drives, enabling more-shrinkable magnetic bits.

WHY IT MATTERS: Increases in storage density have enabled hard drives to capture markets in portable electronics such as MP3 players and, more recently, cell phones. Advances like those by Albrecht and colleagues could improve hard-drive capacities another tenfold or more, which would greatly reduce the physical size of current systems and enable, for instance, a new generation of portable video devices.

Source: Albrecht, M., et al. 2005. Magnetic multilayers on nanospheres. *Nature Materials* 4:203–206.

Sheer Energy

Thinner, cheaper fuel cell catalysts

CONTEXT: Fuel cells are much ballyhooed as the future of energy production. In a fuel cell, hydrogen and oxygen combine to produce electricity and water, but getting them to react in a controllable way requires an expensive platinum catalyst. To make current fuel cell designs economically viable, the amount of platinum used must be reduced by nine-tenths. Now, researchers from Brookhaven National Laboratory and the University of Wisconsin-Madison have shown that using less platinum can lead to a more efficient catalyst. The discovery opens a new route to cheaper, more efficient fuel cells.

METHODS AND RESULTS: Junliang Zhang and colleagues coated five different metals with a layer of platinum one atom thick and tested them in a model system meant to mimic a fuel cell. In such a system, hydrogen and oxygen gases collect on the metal surface, where they react to form water and release electric current. For most of the platinum "monolayers," the reaction occurred more slowly than it does on the thicker platinum layer currently used in fuel cells, but adding a monolayer of platinum to palladium sped up the reaction. To explain their experimental results, the authors simulated the system using a technique called density-functional theory. Their computations predicted how the performance of the platinum monolayer would be affected by atoms from the underlying layer of metal. The theory aligned well with their experiments and showed that adding a platinum monolayer to palladium balances two competing needs: it is reactive enough to break the bonds between oxygen atoms yet does not cling to the oxygen atoms so tightly that it prevents them from reacting with hydrogen.

WHY IT MATTERS: Because fuel cells are efficient and do not directly generate harmful emissions, many expect them to become a source of power for cars, homes, and even portable electronics like cell phones. If the amount of platinum they require can be reduced to a monolayer, commercial fuel cells could enjoy a quick and broad entry into the market. Tailoring the surfaces of metals to boost their catalytic capacities should also have applications in chemical manufacturing and pollution control. If such applications can be found through theoretical analysis, then cleaner, faster, and more efficient production techniques won't take such a toll on research and development budgets.

Source: Zhang, J., et al. 2005. Controlling the catalytic activity of platinum monolayer electrocatalysts for oxygen reduction with different substrates. *Angewandte Chemie International Edition* 44:2132–2135.

COURTESY OF MANFRED ALBRECHT

The Start of Computer Games

Created at MIT, Spacewar inspired future game pioneers.

THE FIRST GAME invented specifically for the computer appeared in early 1962. A new $120,000 computer had just arrived at MIT that was faster and easier to use than the handful of other hulking machines on campus. And a group of young MIT programmers who just happened to be reading science fiction books about space battle had been itching to test it out. In less than a year, the programmers, led by Steven Russell, produced Spacewar, a game complete with rocket-powered spaceships, missiles, gravitational effects, and even an unpredictable "hyperspace" function. Although it was never commercialized, Spacewar inspired those who would bring video games to the masses 10 years later.

As Russell and his friends awaited the arrival of the new computer, a PDP-1 built and donated by Digital Equipment Corporation, they were already thinking about what demonstration programs to write for it. Demonstration programs for earlier computers were not very exciting. One, for example, moved a mouse through a maze that had been created by the user. In another program, the user manipulated console switches to change patterns on the screen. But the MIT programmers wanted to create a game that demanded skill and strategy and kept players engaged for more than a few minutes. Russell had just finished reading a series of books by Edward "Doc" Smith about warriors who zipped across galaxies in spaceships. It didn't take long for the idea to dawn on him and his friends: Spacewar!

The PDP-1 that finally arrived at the end of 1961 was nothing like the other computers Russell had used. For one thing, he could turn it on with the flip of a single switch. And it was the first computer he used that could produce an immediate printout of the code he was entering, saving much time and hassle when he was debugging his program. "I thought this was a lot more interesting, and I wanted to try it," says Russell, now a software engineer with Nohau in Campbell, CA, a company that makes software-debugging tools.



Geek War: Two spaceships (the big spots) fight in Spacewar—shown here on the screen of a restored PDP-1 computer.

COURTESY COMPUTER HISTORY MUSEUM

Working in his spare time, Russell programmed the first version of the two-player game. By flipping switches on the PDP-1 console, each player could rotate and accelerate one of two ships and fire torpedoes against a background of randomly scattered stars. But fellow MIT hackers wanted to make the game more realistic and challenging. Peter Samson encoded the night sky so that the stars appeared in real-life constellations. Dan Edwards programmed a sun in the middle of the screen that exerted gravitational pull on the ships. And J. M. Graetz added the final touch: a function that made the ship disappear into hyperspace and reappear in an unpredictable place on the screen. By the spring of 1962, the first computer game was complete.

Russell considered selling the game. But the only customer would have been Digital Equipment, because his game could run only on the PDP-1. So he let people access the code, and soon programmers began to adapt it to work on other computers, allowing the game to spread across the MIT campus and to other universities. It ended up at the University of Utah, where a student named Nolan Bushnell discovered it in the mid-1960s. In 1971, Bushnell invented a coin-operated arcade game called Computer Space, which resembled Spacewar. It was a commercial failure, but that didn't stop him. A year later, he founded Atari.

After the creation of Spacewar, Russell moved to Stanford University and has since spent his career in the computing and banking industries, including stints with a couple of gaming startups. He's never made any money from Spacewar or any of its descendants, but money wasn't the point. "The main purpose was to see what we could do and see if we could make it work," says Russell. Today, Spacewar lives on. At the Computer History Museum in Mountain View, CA, a group of engineers will soon complete the restoration of a PDP-1, which will be exhibited to the public. Visitors will then get to experience computing history by playing Spacewar for themselves.

Corie Lok

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